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# Some of the More Important Factors Governing the Flight of European Corn Borer Moths to Electric Traps[1]

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Previous investigations of the use of electric traps as a possible method of controlling the European corn borer have given promising results, and the problem of putting this method of control on a more practical basis has been the subject of further investigation. The main factors affecting the flight of the moths to the traps as a means of further increasing the number captured and the percentage of control in the trapped areas have been given primary consideration. These factors include studies on the placement of traps with regard to field contour, the height of trap operation, the trap type and the most effective type of lamp to use as a lure. Such factors bear a close relationship to the cost of installation and operation of any plan for controlling the corn borer by means of electric traps and the practical application of radiant energy.

It has been shown by Hervey & Palm (1935), by Ficht & Hienton (1939), and by Ficht, *et al.* (1940), that European corn borer moths may be captured readily in electric traps. In experiments also reported by the authors in the two last mentioned papers, it was shown that infestations and populations could be greatly reduced but not eliminated by lighting corn fields with one 250-watt, 115-volt, *Mazda CX* lamp per acre. During the course of the 1940 experiments a total of 38,613 corn borer adults, or an average of 3,218 adults per trap, were taken in a 12-acre field by using a plan of field experimentation similar to that used by Ficht, *et al.* (1940). In a second field used during the same season, a slightly less degree of control was secured, due probably to an interruption in the experiment prior to the end of moth flight. It was estimated that the larval population of the 12-acre field was reduced 68 per cent by the use of electric grid traps equipped with 250-watt *Mazda CX* lamps.

Purpose of Study.—The laboratory studies, during 1939 and 1940, were initiated primarily to determine some of the fundamental factors which affect the attractiveness of various lamps to corn borer moths. The phototropic responses of the moths to such factors as ultraviolet radiation, the intensity of the radiant energy, the color of the radiant energy, and the size of the luminous area were observed.

The field experiments conducted during 1940 included three main objectives: determining the effects of trap placement in relation to field contour on the number of moths captured, the optimum height of trap operation, and a more efficient trap structure.

Laboratory and Field Methods.—The factors influencing the flight of corn borer moths to radiant energy were studied by liberating the corn borer moths in an inclosed box 10 feet square and four feet high, the inside of which was painted mat black. The box was provided with apertures each six inches square in the center of each of four sides. This allowed the radiant energy to enter the box from the lamps which were placed outside the apertures. Each aperture was covered with an electric grid which served to kill the moths attracted to the opening by the radiation from that source.

Outside each aperture, a box 48 inches long, 15 inches wide, and 15 inches high

[1] A cooperative project between the Departments of Entomology and Agricultural Engineering of the Purdue University Agricultural Experiment Station and the Bureau of Chemistry and Engineering of the U. S. Department of Agriculture.

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was placed horizontally with one end tight against the side of the big box. The inside of each lamp box was painted white to reflect the light. The equipment for producing and controlling the radiant energy was mounted in these boxes.

In all of the tests except those designed to determine the effect of ultraviolet radiation on attractiveness, *Corex D* filters were used as diffusion plates to provide uniformity of radiant energy over the entire aperture. These filters were placed next to the grids. Between the diffusion plates and the radiant energy source, specially constructed iris diaphrams were used to equalize the size of the luminous area. Intensity was regulated by moving the lamps toward or away from the apertures, as the individual tests demanded. The equipment was similar to that used by Marshall & Hienton (1938).

**Table 1.—Summary of five tests with 250-watt *CX* lamps to determine the effect of intensity of radiation on its attractiveness to corn borer moths.**

| Intensity in foot-candles | 250 | 500 | 1000 | 2000 |
|---|---|---|---|---|
| No. of moths attracted | 22 | 39 | 99 | 185 |

The moths for the tests were collected by hand in vials from concentration cages which had been stocked with infested corn fodder. Attempts were made to introduce about 100 adults for each individual test through an opening in the center of the bottom of the lure chamber.

The field work during 1940 consisted of illuminating 21 acres of dent corn. One 250-watt, 115-volt, *Mazda CX* lamp was installed in an electrocutor trap on each acre. One block of nine acres of rolling topography was used to study the effect of placing traps at different levels in the field. The electrocutor traps were all of one type and were operated at a height of 10 feet above the soil surface. Three traps were placed on each of three levels.

The second block was a field of 12 acres, with three rows of four lamps each. Four types of traps were used, and these were operated at 5, 10 and 15 feet above the soil surface. The four trap types were alternated in position as well as height each night.

All traps were examined daily. The number of moths caught in each trap were sexed and counted in the varying types, heights, levels of contour, and trap positions.

EFFECT OF INTENSITY OF RADIATION SOURCE ON ATTRACTIVENESS.—A factor which affects the attractiveness of lamps is the intensity of the radiant energy in the region of the spectrum visible to the human eye. *Corex D* diffusion plates were used to produce an even diffusion of radiant energy through the apertures, and the variation in intensity was produced by regulating the distance at which the lamps were placed from these filters. The luminous areas were equal in size.

Laboratory tests on the effect of intensity of radiant energy included a series of five experiments in which there were four sources of visible light at 250, 500, 1,000 and 2,000 foot-candles of intensity, respectively. In these tests 250-watt, 110-volt *Mazda CX* lamps were used. The relative number of moths attracted to the various sources is given in table 1. These figures show that the catches were in about the same ratio as that of the intensities, namely 1, 2, 4, and 8. Other tests conducted at both lower and higher intensities indicate clearly that the moths will select the source of radiant energy of the highest intensity. Intensities equal to bright sunlight (10,000 F. C.) were used.

EFFECT OF SIZE OF THE LUMINOUS AREA ON ATTRACTIVENESS.—The effect of varying the size of the luminous area on the attractiveness of different sources of radiant energy to the corn borer moths was determined by holding the intensity of 250-watt *Mazda CX* lamps at 750 foot-candles and regulating the size of the luminous areas by means of specially constructed diaphragms. *Corex D* filters were used to diffuse the radiant energy over the apertures. Four sources of visible light were used in these tests with luminous areas adjusted in the proportion of 1, 2, 4, and 8 at each aperture.

**Table 2.—Summary of two tests to determine the effect of varying the size of the luminous area on attractiveness to corn borer moths.**

| Diameter of area (inches) | 2.0 | 2.83 | 4.0 | 5.66 |
|---|---|---|---|---|
| No. of moths attracted | 21 | 46 | 81 | 109 |

The size of the luminous areas and the respective number of moths attracted to each are given in table 2. These tests indicate clearly that the size of the luminous

area is of importance since the larger the diameter used, the greater is the number of moths attracted.

ATTRACTIVENESS OF ULTRAVIOLET RADIATION.—Thirteen tests were made to determine the value of ultraviolet radiation as an attrahent to the moths.

In 10 of the tests *S-4* lamps were used as the source of radiant energy. These lamps were operated with *Corex D* filters which allowed the ultraviolet to pass, in comparison with lead glass filters which screened out most of the ultraviolet radiation. Tests with an ultraviolet meter showed that the lead glass filter screened out ultraviolet radiation shorter than 3,200 Ångstrom units. The results of these tests, which are given in table 3, indicate that the presence of ultraviolet radiation of 2,967 Ångstrom units does not increase the attractiveness of the light source and that the moths had no preference for radiation in which ultraviolet energy of that wave length was present.

When the *H-4* lamps were used, with and without ultraviolet radiation below 3,200 Ångstrom units, the reactions of the moths were similar to those secured with the *S-4* lamps. In the use of both of these lamps the number of moths attracted to the radiant energy sources was less when the lead glass filters were used. Not only did the moths have no preference for ultraviolet radiation under the conditions of these experiments but slightly fewer moths were attracted to those sources of radiant energy in which ultraviolet below 3,200 Ångstrom units was present.

**Table 3.—Summary of the tests to determine the attractiveness of ultraviolet radiation to corn borer moths.**

| No. of Tests | Lamp Used | No. of Moths Attracted with | |
|---|---|---|---|
| | | Ultraviolet Present | No Ultraviolet |
| 3 | *H-4* | 83 | 93 |
| 10 | *S-4* | 305 | 345 |

EFFECT OF COLOR OF RADIANT ENERGY ON ATTRACTIVENESS.—Another important factor in the attractiveness of various lamps to borer adults is color. In these experiments, *H-4* and *S-4* lamps having a high percentage output in the violet and blue bands of the visible spectrum and a low output in the orange and red bands were compared to *Mazda CX* and *Mazda* flood-lights which have a lower percentage output in the violet and blue band and a greater output in the orange and red bands. The percentage radiation output of the 250-watt *CX* and the 100-watt *H-4* lamps in these spectral bands is given in table 4. The radiation output of the *Mazda* flood-light is essentially similar to that of the *Mazda CX* lamp, and the radiation output of the *S-4* lamp closely approximates that of the *H-4* lamp. These tests on effect of color differences were run at equal visible intensities of the 1,000 foot-candles.

**Table 4.—Per cent of over-all input radiated in different spectral bands of 250-watt *CX* and *H-4* lamps.[3]**

| Wave Lengths in Ångstroms | Type of Lamp | |
|---|---|---|
| | 250-Watt *CX* | 100-Watt *H-4* |
| 3800 to 5900 (Violet and blue) | 1.21 | 4.5 |
| 5000 to 6030 (Green and yellow) | 2.8 | 5.5 |
| 6000 to 7600 (Orange and red) | 7.9 | 0.82 |

[3] Data taken from General Electric Review, Vol. 42, No. 12: 540–543.

The important observation regarding these tests is that the moths were attracted in greater numbers to lamps radiating the greater percentage of their visible energy in the violet-blue band of the spectrum, than to lamps radiating the greater percentage of their visible radiation in the orange-red band of the spectrum. The number of moths attracted by each of the different lamps in these tests is shown in table 5. In these tests in which factors affecting attractiveness other than color were eliminated, approximately 92 per cent of the moths, reacting to the radiant energy provided in the lure chamber, chose the radiation sources with the highest proportion of violet and blue.

In a second study of color as an attrahent for the moths, four lamps of the ordinary *Mazda* tungsten filament type having lengths of life of 25, 100, 500 and 1,000 hours respectively were used at equal visible radiation intensities of 50 foot-candles. The relative attractiveness of these lamps as a source of radiant en-

ergy is given in table 5 and the per cent of total light emitted by each in the various color bands is given in table 6. The relative attractiveness of these sources of radiant energy varied with the length of life of the lamps, the greatest number of moths being attracted to the lamps having the shortest length of life. The least nearly three times as attractive as the 1,000-hour lamp.

Additional tests, with a 200-watt dark blue lamp which emits a large percentage of its radiant energy in the violet and blue band of the visible spectrum, were made in comparison with the *H-4* lamp in the violet and blue wave band between

**Table 5.—Summary of the tests to determine the reactions of corn borer moths to radiant energy color.**

| No. of Tests | | | | | | Intensity in Foot-Candles |
|---|---|---|---|---|---|---|
| | Lamp used | 250-watt flood | 100-watt *S-4* | 100-watt *H-4* | 250-watt *CX* | |
| 2 | Moths attracted | 6 | 77 | 92 | 9 | 1000 |
| | Lamp used | 100-watt 24 hr. | 100-watt 100 hr. | 100-watt 500 hr. | 100-watt 1000 hr. | |
| 2 | Moths attracted | 58 | 46 | 23 | 21 | 50 |
| | Lamp used | 200-watt dark blue | 100-watt *H-4* | 250-watt *CX* | | |
| | Moths attracted | 51 | 8 | 2 | 0 | 1.5 |
| | | 52 | 7 | 4 | 0 | 5.5 |

number of moths were attracted to the lamps having the longest life. Since the visible radiation intensities and the size of the luminous areas were equal in these tests, and the effect of brilliance, due to the variable lengths of life of the lamps, was largely eliminated by the use of *Corex D* diffusion plates, the difference in attractiveness was thought to be due primarily to color. It will be noted that of the total radiant energy output of these lamps, the 25-hour lamp produces the highest proportion in the violet-blue band

**Table 6.—Per cent of total light from 100-watt lamps with varying lengths of life.**

| Wave Band | 100-Watt Mazda Lamp | | | |
|---|---|---|---|---|
| | 25 hr. | 100 hr. | 500 hr. | 1000 hr. |
| Violet and blue | 3.0 | 2.9 | 2.6 | 2.3 |
| Green | 43.8 | 43.1 | 41.6 | 40.7 |
| Yellow | 26.5 | 26.5 | 26.6 | 27.4 |
| Orange and red | 26.7 | 27.5 | 28.2 | 29.6 |

and the lowest proportion of radiation in the orange-red band. The opposite occurs in the 1,000-hour lamp, and this lamp was the least attractive. The 100-hour and 500-hour lamps were intermediate in respect to both color characteristics and attractiveness. The 25-hour lamp was 3,800 and 5,000 Ångstrom units. Further evidence of the superiority of violet and blue radiation as a lure for corn borer moths is noted by the fact that in a comparison of these three lamps, the dark blue lamp attracted 101 moths as compared to 15 for the *H-4* and four for the *Mazda CX*. Luminous areas and intensities were equal in these experiments. The intensity of visible radiant energy of the dark blue lamp is relatively low. In the equipment used in these experiments the maximum number of foot-candles obtainable from the 200-watt dark blue lamp was 5.5 at a distance of approximately six inches from the aperture to which the moths were attracted. While this lamp is superior to other lamps tested in attracting corn borer moths where intensities were equalized, a comparison of these lamps under ordinary operation showed the *H-4* and *Mazda CX* lamps superior to the dark blue lamp. This is due to the relatively low radiation intensity of the dark blue lamp. The greater intensities of the other two lamps would overcome the advantage of color in the dark blue lamp when operated without intensity equalization or control.

Relation of Field Contour to Effectiveness of Traps.—The advantage

or disadvantage of placing the light traps on the lower or higher areas of a corn field was studied in a nine-acre plot. A rolling field was surveyed, and the supporting poles were placed equidistant on the same topographic level. The traps, suspended from these poles, were operated at a uniform height of 10 feet from the ground level. One trap, or three to each level, equipped with a 250-watt, 115-volt *CX* lamp was used per acre. Three levels were used, and these were chosen so that there was little possible advantage to any one series of the low, intermediate and high levels of lights with regard to the prevailing wind direction. There was a difference of 5.5 feet in the height of each of the three levels of lights.

A total of 10,674 corn borer adults were captured during the duration of the observations on this experiment. It is evident from the figures presented in table 7 that there is a significant difference in the number of moths taken on the higher

**Table 7.—Field catch of corn borer moths on high, intermediate, and low contours in a corn field.**

| POSITION | TOTAL MOTHS | MOTHS PER TRAP |
|---|---|---|
| High contour | 3,983 | 1,326.3 |
| Intermediate contour | 3,935 | 1,311.7 |
| Low contour | 2,756 | 918.7 |

contours of the field as compared to the low contour, with the traps situated on the higher contours of the field having a distinct advantage. There was no significant difference in the moth captures from the high and intermediate contours. This may be accounted for by differences in the corn heights which averaged 62.6, 67.7, and 63.1 inches in height for the high, intermediate, and low contours respectively. The influence of the height of the corn under and immediately surrounding the traps on moth catches have been discussed by Ficht & Hienton (1939).

HEIGHT OF TRAP PLACEMENT ABOVE THE GROUND.—A level field of dent corn was used for studies on the relation of trap height above the ground level to attractiveness for corn borer moths. Three of each of four types of traps were suspended at heights of 5, 10, and 15 feet in three series of four traps, each at the rate of one per acre, making a total of 12 acres of corn used in the experiment. The height of the traps in each series was alternated each night to allow for any variations in catches which might be due to elevation.

The figures on the moth catches given in table 8 show distinctly that the lower

**Table 8.—Number of moths captured at three heights of trap placement above the soil surface in a level field.**

| POSITION | TOTAL MOTHS | MOTHS PER TRAP |
|---|---|---|
| 5 feet above soil | 3,652 | 913 |
| 10 feet above soil | 2,196 | 549 |
| 15 feet above soil | 1,324 | 331 |

the traps are placed above the level of the soil, the greater are the catches, providing such traps are placed above the top level of the corn.

As the corn reached the level of the lowest trap placement of 5 feet and operation continued thereafter at that corn level, there was evidence that this position was superior to the higher positions. While the traps placed at the lowest level of 5 feet above the soil surface captured the most moths during the period when the corn had not yet reached 5 feet in height, the lowest traps continued to capture the most moths when they were raised to corn level as the corn exceeded the 5-foot height.

TYPES OF FIELD TRAPS.—Due to accumulations of borers occurring under and in the immediate vicinity of traps in previous field experiments, and following observations to the effect that the moths frequently circle the traps in close proximity to the trap grids and later drop into the corn unharmed, three additional types of traps of different structure were tested against the standard cylindrical form that had previously been used. Two of the three were modifications of the plain cylindrical grid type. One modification consisted of two vertical galvanized baffle plates which were placed on either side of the grid and extended outward for 6 inches. A second modification consisted of a vertical electrified grid extending outward for 6 inches on one side of the standard circular grid. The additional trap was of the flat type with the lamp placed on one side in the approximate center of the grid.

Three traps of each type were used. One of each was used in each of three series, and they were alternated systematically each night in both position and height.

A total of 38,613 moths were taken from these traps during the season. While some differences occurred in the number of adults taken in the various types of traps, such differences are not significant under the conditions of this experiment (Table 9). It is thought, after further observations on corn borer moth flight to electric grid traps, that proper placement of the traps in relation to corn heights might eliminate much of the accumulation of larvae occurring in the plants under and immediately surrounding the light traps.

**Table 9.—Number of moths captured in four types of traps used during 1940.**

| Type of Trap | First Generation Moths | Second Generation Moths | Total Moths |
|---|---|---|---|
| Circular circular grid | 1,847 | 8,139 | 9,986 |
| Standard cylindrical grid with side grid | 1,787 | 7,896 | 9,683 |
| Standard cylindrical grid with baffle plates | 1,850 | 8,003 | 9,853 |
| Flat | 1,824 | 7,267 | 9,091 |

EXPERIMENTAL RESULTS.—The basic results secured from these studies on some of the more important factors influencing the flight of corn borer moths to electric traps have shown that the moths prefer certain color bands of the visible spectrum. The violet-blue band proved the most attractive. In a comparison of *H-4* and *CX* lamps it was found that the *H-4* lamp, from which the percentage of overall input radiated in the violet and blue spectral bands was approximately four times the percentage of these colors radiated by the *CX* lamp, attracted approximately 10 times as many moths as did the *CX* lamp.

Ultraviolet radiation below 3,200 Ångstroms did not add to the attractiveness of lamps as a lure for corn borer moths, and the moths showed no preference for lamps radiating ultraviolet energy of 2,967 Ångstrom units.

The size of the luminous area is of some importance in attracting the moths. An increase in the ratio of the size of the luminous area from one to eight times increased the attractiveness of the radiant energy source approximately five times.

The intensity of the source of the radiant energy in the region visible to the naked eye is an important factor affecting the attractiveness of lamps to the European corn borer. The number of moths attracted to the radiant energy was in almost direct proportion to the intensity of light visible to the human eye.

Field studies indicated that the corn borer moths showed a preference for those traps which were placed on the high spots of the field when corn heights were about equal. Moths were captured in the greatest numbers when the traps were operated just above the level of the corn.

No significant difference was noted in catches from four types of traps having differently shaped electrocutor grids.—4-21-40.

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ANNUAL MEETINGS—EASTERN BRANCH
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# Resistance of Corn Strains to the Southern Corn Rootworm, *Diabrotica duodecimpunctata* F.[1]

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The southern corn rootworm, *Diabrotica duodecimpunctata* F., is responsible for a great deal of lodging in corn fields throughout the Corn Belt. The resistance or susceptibility of strains of corn to this insect has been observed at several locations in Illinois over a three-year period, 1937 through 1939.

Because it has not been possible to obtain efficient and economical control of root feeding by the southern corn rootworm on a field basis in the Corn Belt by cultural practices, insecticides, or other commonly used methods it is necessary to seek another solution of the problem. The data summarized here indicate the possibility of reducing the injury by the use of resistant strains of corn.

HISTORICAL STATEMENT.—Injury to corn roots, which was undoubtedly due to the southern corn rootworm, was first reported by Yancey in 1828 (Webster 1892; Yancey 1828). Insect damage to the roots of corn, which, according to the descriptions was typical rootworm feeding, was reported numerous times from 1828 to 1888 without being associated with this insect. The relation between the larva doing this damage and the adult of this species was probably first recognized by Riley in 1883 (Garman 1891; Riley 1891) when he reared the beetles from larvae sent to him after being collected where they were causing the damage that was commonly called "budworm" or "drillworm" damage. Webster (1888) first associated *Diabrotica duodecimpunctata* with "budworm" damage to corn in the field in 1887. Previous to that time the insect was generally considered a pest of cucurbits, legumes, fruit trees, and various flowers and was commonly known as the squash beetle, melon beetle, 12-spotted Diabrotica, or 12-spotted cucumber beetle. The name spotted cucumber beetle is now recognized as an alternate common name for the insect by the American Association of Economic Entomologists. This insect was first reported as a pest of corn in Illinois by Forbes (1892). However, the kind of damage this insect does was recognized by Forbes (1894) as early as 1886, although the damage was not then associated with the southern corn rootworm.

No records of any attempts to measure the damage actually caused by the feeding by the southern corn rootworm on the roots of corn were found in the literature. Forbes (1892) described the lodging that occurs following the root damage. He also stated that the injured plants mature slowly, remain green longer than the average, and often are subjected to injury by frost.

Resistance to southern corn rootworm of certain double crosses has been reported by Bigger *et al.* (1938).

LIFE HISTORY.—The life history of the southern corn rootworm in the Corn Belt is not entirely known. Isely (1929) and Arant (1930) have reported on life history studies in Arkansas and Alabama, respectively. Sweetman (1926) worked on the life history in Iowa in 1924, and reported only one generation in that particular season. However, Sweetman points out that the season in which his studies were made was characterized as being cold and rainy during the spring and summer, and these conditions may have been responsible for the development of only one generation. Forbes (1896), Luginbill (1918), and others believed that this insect has two generations each year. Observations made in Illinois have indicated that the southern corn rootworm has two generations in those years when it is a factor in reducing corn production. In general the adults have first appeared in May. Newly hatched larvae have been observed feeding on corn roots soon thereafter. Many full grown larvae and pupae have been observed on corn roots during the first half of July. Adults appeared in the field again the first part of August.

[1] Cooperative investigations of the Illinois Natural History Survey, the Division of Cereal Crops and Diseases, Bureau of Plant Industry, the Division of Cereal and Forage Insect Investigations, Bureau of Entomology and Plant Quarantine, U. S. Dept. of Agriculture, and the Illinois Agricultural Experiment Station.

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Eggs deposited by some of these females gave rise to young larvae, most of which were in the prepupal and pupal stage early in September. Adults again appeared in the field the last half of September and early October.

FIG. 1.—Effect of lodging on the pollination of corn. (Left) Ear from erect plant where pollination was normal, (center) ear from plant that had lodged before plollination, and (right) ear from erect plant in crossing field where the pollen plants had lodged before pollination had been completed.

The life history indicated above is supported by records made during examinations of corn roots in connection with crop rotation studies at several points in Illinois during the past ten years and reported by Bigger & Flint (1939). Additional support is furnished by an observation near Springfield, Ill., in 1938. On September 14 a field of rye was reported as being attacked by some insect. Several larvae were collected and reared, southern corn rootworm adults emerging from them October 3 and 5. The field was visited September 21 when both larvae and pupae were present. The field was visited again October 13, when it was impossible to find the insects present in any form in or near the field. They apparently had matured and left the neighborhood.

It has been concluded by the present authors, from observations made in Illinois, that the southern corn rootworm adults usually migrate to the Corn Belt in the spring from the South as described by Smith & Allen (1932), and that frequently two generations are produced during the summer.

DAMAGE TO PLANTS.—Throughout its range south of Illinois the southern corn rootworm is recognized as an early-season pest of corn. The damage, which is inflicted while the plants are small and which frequently kills them, results from the burrowing of the larvae into the growing bud near the surface of the soil. This type of damage is responsible for the name "budworm" or "drill-worm" applied to the insect in the South.

Damage to corn in the Corn Belt consists of root pruning and tunneling and occurs after the plants are more advanced in growth. This type of damage was described by Webster (1913) when he stated that roots and stems below the ground were grooved, furrowed and perforated. It was also recognized by Luginbill (1918)

FIG. 2.—Corn plants injured by the feeding of adults of the southern corn rootworm.

when he stated that in older corn the worms injure the roots almost exclusively.

Lodging of the plants frequently has a direct effect upon pollination of ears in the field. This is especially important in

fields where hybrid seed corn is being produced. Where the plants are erect satisfactory pollination is possible and well filled ears ordinarily result. If the ear parent is badly lodged pollen may fall only on the upper silks and a portion of those on the lower side of the ear will not be pollinated. If the pollen parent is lodged so that tassels are lower than the silks to be pollinated, incomplete pollination may result and poorly filled ears with irregular or round kernels may be obtained. These conditions are illustrated in figure 1.

FIG. 3.—A susceptible hybrid that lodged following injury by the southern corn rootworm.

The increased use of mechanical harvesters during recent years has intensified the demand for corn plants that will resist lodging and that will remain firmly anchored in the soil through the harvesting season. Fields were observed in 1937 in which the plants were so insecurely anchored following severe rootworm attack that it was necessary to harvest the corn by hand, although a mechanical harvester was available. In all cases this condition occurred where open-pollinated varieties or rootworm susceptible hybrids were grown. Apparently very little difficulty was encountered with mechanical harvesters where rootworm resistant hybrids were grown.

CONTROL OF THE INSECT.—During the period that the insect has been recognized as a pest, various methods have been recommended for the reduction or avoidance of the damage it causes. Among them are: early plowing (Arant 1930); late planting (Chittenden 1905; Forbes 1892); avoidance of low, wet ground (Smith 1908; Symons 1906); planting a large number of kernels per hill (Gossard 1908). It is recognized (Garman 1889) that rotation is not effective in reducing damage, although it has been recommended with reservations. These practices may reduce the early-season damage by the larvae, but do not prevent the destructive midseason attack on the roots. The development and use of strains of corn resistant to damage by the insect appears to be the only practical method of combating it during midseason.

EXPERIMENTAL RESULTS.—Since 1937 studies have been confined largely to inbred lines and single crosses.[1] The data reported here were obtained at several different locations in Illinois during a three-year period. In 1937 data were obtained from the Dunn farm, north of Urbana, and from the Agronomy farm, south of Urbana. The plots on the Dunn farm were single rows ten hills long, the strains being replicated four times. On the Agronomy farm a single 15-hill row of each strain was grown. In 1938 the test fields

[1] The writers are indebted to G. H. Stringfield, W. J. Munn and W. H. Freeman for some of the seed used in these studies.

were located near Pana, in south-central Illinois, and near McClure, in extreme southern Illinois. In the Pana experiment a single 15-hill row of each strain was grown. In the McClure experiment the plots were 1 by 10 hills and each strain was replicated three times. In 1939 data were obtained from plots grown near McClure, Ill. The inbred lines were grown in plots 1 by 10 hills which were replicated four times, and the single crosses in plots 2 by 10 hills, replicated five times.

Table 1.—Effect of lodging in corn caused by the southern corn rootworm, 1937.

| | Average of Six Samples, 25 Plants Each | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Degree of lodging | Plants in field | Ear weight air dry | Moisture in ears | Bushel test weight | Average ear length | Average ear diameter | Ears poorly filled | Unsound corn |
| | % | Lbs. | % | Lbs. | Inches | Inches | % | % |
| Erect | 55 | 18.9 | 19.3 | 57.5 | 9.0 | 2.1 | 2.0 | 0.3 |
| 45° | 35 | 15.5 | 22.4 | 57.0 | 7.9 | 2.0 | 26.7 | 0.9 |
| 90° | 10 | 9.1 | 25.4 | 54.7 | 6.5 | 1.8 | 50.0 | 4.1 |

Table 2.—Percentage of inbred plants showing leaf injury caused by the feeding of adult *Diabrotica duodecimpunctata* F., Urbana, Ill. 1937.

| | Per Cent Plants Injured | | |
|---|---|---|---|
| Inbred Line | Dunn Farm | Agronomy Farm | Average |
| Ill. 5679 | 30.8 | 21.9 | 26.4 |
| Ill. 2204 | 40.3 | 14.0 | 27.2 |
| Kan. Kys | 25.4 | 30.6 | 28.0 |
| Ill. A | 40.5 | 17.4 | 29.0 |
| Ill. 5675 | 19.2 | 44.4 | 31.8 |
| Kan. K4 | 35.2 | 33.1 | 34.2 |
| Ill. K | 48.5 | 20.0 | 34.3 |
| Ill. Hy | 49.4 | 28.5 | 34.5 |
| Ill. 90 | 32.4 | 37.4 | 34.9 |
| Ind. Tr | 51.4 | 19.0 | 35.2 |
| Ia. Pr | 26.4 | 46.6 | 35.6 |
| Ill. 4451 | 49.2 | 27.1 | 38.2 |
| Ind. 38-11 | 36.4 | 40.9 | 38.7 |
| Ill. R4 | 37.0 | 42.4 | 39.7 |
| Ill. 4211 | 44.1 | 46.2 | 45.2 |
| Ill. 5120 | 63.2 | 31.7 | 47.5 |
| Ia. I198 | 61.6 | 34.8 | 48.2 |
| U. S. 540 | 46.4 | 56.1 | 51.3 |
| Ia. L317 | 37.1 | 69.3 | 53.2 |
| Ia. 701 | 52.7 | 60.7 | 56.7 |
| Ill. 5676 | 67.1 | 48.6 | 57.8 |
| Ind. WF9 | 60.0 | 69.7 | 64.9 |
| Average | 43.0% | 38.2% | |
| Range | 19.2–67.1% | 14.0–69.7% | |

During 1937 data were taken on adult feeding and on lodging due to larval feeding. The beetles attacked the young corn in both fields at Urbana, and a definite preference for certain strains was observed, both in the percentage of plants injured and in the intensity of the injury. This type of damage is shown in figure 2. Since the intensity of the injury seemed to be rather closely associated with the percentage of plants injured, the latter has been used as a criterion for measuring resistance. Resistance of corn strains to larval attack has been measured by the amount of lodging that has occurred in fields known to be infested (Fig. 3).

During the last two years records also have been made of the percentage of plants lodged 45 degrees or more at McClure. These records are not included because of the comparatively small amount of data procured.

During 1937 an attempt also was made to measure the seriousness of southern corn rootworm damage to open-pollinated varieties of corn at six different locations where severe rootworm feeding had occurred. Ears were harvested from 25 plants that were erect, 25 plants lodged at a 45 degree angle and 25 plants lodged at a 90 degree angle at each of the six locations. Thus, the data shown for each type of lodging represent an average of 150 plants. The samples for this study were harvested between October 10 and 15, following a period of dry weather. Therefore, the high moisture content of ears from plants completely lodged was not due to weather conditions, but rather to delayed maturity which was considered to be the result of severe rootworm feeding. The data obtained are presented in table 1. It was found that, as the degree of lodging increased, the percentage of moisture in the ears, the percentage of ears poorly filled, and the percentage of unsound corn also increased and the weight of the ears, length and diameter

**Table 3.—Differential lodging of inbred lines with yellow endosperm color following attack by the southern corn rootworm.[1]**

| INBRED LINE | PER CENT PLANTS LODGED 30 DEGREES OR MORE | | | | | | |
|---|---|---|---|---|---|---|---|
| | Dunn Farm Urbana 1937 | Agronomy Farm Urbana 1937 | Pana 1938 | McClure 1938 | McClure 1939 | Average[2] Three Station Years | Average[3] Five Station Years |
| Ind. 38-11 | 0.0 | 0.7 | 0.0 | 25.9 | 0.0 | 8.6 | 5.3 |
| Kan. Kys | 9.3 | 15.4 | 48.3 | 10.9 | 4.1 | 21.1 | 17.6 |
| Kan. K4 | 3.0 | 14.4 | 16.7 | 72.2 | 0.0 | 29.6 | 21.3 |
| Ind. B2 | 10.1 | — | 88.9 | 0.0 | 0.0 | 29.6 | — |
| U. S. 187-2 | — | — | 70.4 | 32.1 | 7.4 | 36.6 | — |
| U. S. 540 | 23.0 | 32.7 | 100.0 | 15.9 | 0.0 | 38.6 | 34.3 |
| Ill. Hy | 9.8 | 0.0 | 68.0 | 56.0 | 1.3 | 41.8 | 27.0 |
| Ind. WF9 | 38.8 | — | 66.7 | 40.0 | 23.6 | 43.4 | — |
| Ia. Pr | 53.6 | 39.8 | 53.3 | 66.0 | 17.6 | 45.6 | 46.1 |
| U. S. 4-8 | — | 30.9 | 95.7 | 48.2 | 0.0 | 48.0 | — |
| Ill. 5120 | 39.7 | 14.9 | 62.1 | 79.3 | 15.9 | 52.4 | 42.4 |
| Ia. L317 | 12.1[4] | 23.9 | 95.8 | 60.8 | 7.7 | 54.8 | 40.1 |
| Ill. R4 | 57.1 | 17.5 | 93.3 | 32.8 | 42.1 | 56.1 | 48.6 |
| Ill. 5675 | 46.1 | 11.8 | 100.0 | 46.0 | 37.7 | 61.2 | 48.3 |
| Oh. 02 | — | — | 86.7 | 70.9 | 30.3 | 62.6 | — |
| Ill. 5679 | 5.2 | 0.0 | — | — | 0.0 | | |
| Ia. 701 | 5.5 | 6.8 | — | 0.0 | 0.0 | | |
| Ia. I198 | 9.9 | 2.4 | — | — | — | | |
| Ill. 4211 | 11.4 | 17.8 | — | 66.7 | 11.6 | | |
| Wis. CC6 | 15.2 | 5.6 | — | — | — | | |
| Ill. 4226 | 18.8 | 4.2 | — | 71.7 | 2.8 | | |
| Ill. 5678 | 19.6 | 4.7 | — | 95.3 | 13.0 | | |
| Wis. CC2 | 19.7 | — | — | — | — | | |
| Ind. L9 | 27.6 | — | — | — | — | | |
| Ind. Tr | 34.2 | 41.7 | — | 82.5 | 44.3 | | |
| Ill. 5676 | 37.5 | 10.7 | — | — | — | | |
| Ind. 66 | 40.2 | — | — | — | — | | |
| Ill. 4451 | 47.4 | 3.5 | — | — | — | | |
| Ill. A | 56.6 | 0.0 | 66.7 | — | — | | |
| Ill. 2204 | 57.3 | 4.7 | 93.3 | — | — | | |
| Ill. K | 69.4 | 20.3 | — | — | — | | |
| Ill. 90 | 80.4 | 62.2 | — | — | 15.6 | | |
| Oh. 51 | 81.1 | — | — | — | 79.1 | | |
| Ill. 5677 | — | 0.8 | — | — | — | | |
| Ia. Mc401 | — | 1.7 | 73.3 | — | — | | |
| Ia. Os420 | — | 3.0 | — | — | — | | |
| Ill. A48 | — | 5.2 | — | — | — | | |
| Wis. CC5 | — | 5.4 | — | — | — | | |
| Ia. I205 | — | 6.3 | 30.0 | 57.1 | — | | |
| Ill. N14 | — | 6.4 | — | — | — | | |
| Wis. CC7 | — | 6.9 | — | — | — | | |
| Ind. 461-3 | — | 8.0 | — | — | — | | |
| Wis. CC1 | — | 8.7 | — | — | — | | |
| Ia. Os426 | — | 32.2 | — | — | — | | |
| Ia. Bl349 | — | 52.9 | — | — | — | | |
| Ia. L289 | — | 59.8 | — | — | — | | |
| Kan. K166 | — | — | 54.5 | 45.0 | — | | |
| Oh. 28 | — | — | 72.4 | 26.5 | — | | |
| Oh. 07 | — | — | 89.7 | 75.9 | — | | |
| Oh. 56 | — | — | 100.0 | 98.5 | — | | |
| Ia. I159 | — | — | 81.8 | 31.0 | — | | |
| Oh. 67 | — | — | 35.7 | 28.3 | — | | |
| Oh. 26 | — | — | 95.5 | — | — | | |
| Ia. Bl345 | — | 73.3 | 100.0 | — | — | | |
| Ia. I224 | — | 41.5 | 100.0 | — | — | | |
| Oh. 15-6 | — | — | — | 8.3 | — | | |
| U. S. 61R5 | — | — | — | — | 0.0 | | |
| U. S. 7 | — | — | — | — | 0.0 | | |
| U. S. 2 | — | — | — | — | 0.0 | | |
| U. S. 6 | — | — | — | — | 1.5 | | |
| U. S. 11RA | — | — | — | — | 3.1 | | |

Table 3.—Continued

| Inbred Line | Per Cent Plants Lodged 30 Degrees or More: Dunn Farm Urbana 1937 | Astronomy Farm Urbana 1938 | Pana 1938 | McClure 1038 | McClure 1938 | Average[2] Three Station Years | Average[3] Five Station Years |
|---|---|---|---|---|---|---|---|
| U. S. 1 | — | — | — | — | 5.7 | | |
| Ind. P8 | — | — | — | — | 7.9 | | |
| Tenn. J8-6G | — | — | — | — | 27.9 | | |
| Oh. 40B | — | — | — | — | 44.2 | | |
| U. S. 5 | — | — | — | — | 49.4 | | |
| Ind. R94 | — | — | — | — | 41.2 | | |
| Tenn. J7-2E | — | — | — | — | 82.0 | | |

[1] *Diabrotica duodecimpunctata* F. [2] Average of per cent lodged at Pana 1938, and McClure 1938, and 1939.
[3] Average of per cent lodged at all stations. [4] Lodged badly soon after count taken.

of ears, and the bushel test weight of the shelled grain, decreased.

The term lodging, as used in this paper, refers only to that occurring as a result of the failure of the root systems to hold the plants erect and includes only plants showing evidence of insect damaged root systems. Plants leaning 30 degrees or more from the perpendicular were considered as "lodged."

The feeding preference of southern corn rootworm adults for the leaves of certain inbred lines is clearly shown in table 2. The extent of leaf feeding in the two fields was very similar with averages of 43.0 and 38.2 per cent of the plants injured, and a range among the inbred lines tested of from 19.2 to 67.1 and from 14.0 to 69.7 per cent of injured plants, respectively. There is little indication of agreement between the two fields in the amount of leaf damage suffered by the different lines. Furthermore, these preferences of the adults do not appear to be correlated with the amounts of damage done to the different lines by the larvae.

The amount of lodging occurring in the various strains of corn following root feeding by larvae of the southern corn rootworm is shown in tables 3 to 11 inclusive. The data relating to the lines with yellow endosperm have been separated from those on the lines with white endosperm. This was done because comparable averages of the two groups could not be obtained.

**Table 4.—Differential lodging of the single crosses of certain inbred lines following attack by southern corn rootworm. Data covering five station years in Illinois.[1]**

| Common Parent | Average Percentages of Plants Lodged 30 Degrees or More in the Numbers of Single Crosses, at the Stations, and in the Seasons Indicated: Dunn Farm Urbana, 1937 | Agronomy Farm Urbana, 1937 | Pana 1938 | McClure 1938 | McClure 1939 | Average Five Station Years |
|---|---|---|---|---|---|---|
| Ind. 38-11 | 16.7 (4)[2] | 6.8 (6) | 53.0 (17) | 64.6 (17) | 3.8 (11) | 29.0 |
| Kan. Kys | 61.2 (1) | 30.1 (6) | 60.3 (8) | 50.3 (3) | 14.8 (8) | 43.3 |
| Ind. WF9 | 40.3 (4) | 21.2 (9) | 62.2 (17) | 64.6 (5) | 32.6 (11) | 44.2 |
| Ia. Pr | 44.0 (3) | 23.7 (12) | 90.1 (1) | 62.7 (1) | 13.3 (2) | 46.8 |
| U. S. 540 | 57.8 (3) | 19.9 (5) | 90.0 (17) | 59.0 (7) | 10.8 (6) | 47.7 |
| Ia. L317 | 63.2 (7) | 20.6 (16) | 68.6 (17) | 79.0 (11) | 11.6 (12) | 48.6 |
| Ill. Hy | 46.1 (10) | 27.4 (16) | 76.2 (17) | 82.5 (6) | 19.9 (14) | 50.4 |
| Ill. R4 | 73.2 (18) | 32.9 (26) | 82.0 (9) | 71.8 (11) | 26.3 (11) | 57.2 |
| Ill. 5120 | 58.2 (6) | 26.8 (28) | 67.5 (8) | 86.4 (6) | 10.2 (4) | 59.8 |
| U. S. 4-8 | 54.2 (2) | 59.1 (5) | 84.0 (8) | 72.9 (1) | 38.4 (6) | 61.7 |
| Kan. K4 | 28.3 (2) | 50.9 (6) | — | 84.8 (2) | 7.2 (6) | 42.8[3] |
| Aver. of crosses represented | 57.5 (43) | 28.5 (103) | 71.1 (83) | 70.0 (46) | 20.8 (62) | |
| Range | 10.9 to 94.8 | 0.7 to 75.1 | 6.3 to 100 | 24.6 to 98.4 | 0.0 to 66.2 | |

[1] See text page 611. [2] Number in parentheses indicates number of crosses involved. [3] Average four station years.

The average percentages of plants lodged, of the yellow inbred lines, in each test are shown in table 3. Three-station-year averages were computed for 15 of the lines and five-station-year averages were computed for 10 of the lines. The behavior of many of the lines was rather variable. In a few cases, lines that were resistant in one test also were resistant in other tests, and likewise those that were susceptible in one test also were susceptible in other tests. The line, Ind. 38-11, was very resistant to lodging following southern corn rootworm attack. This resistance also is transmitted to hybrid combinations as is shown in table 6.

Lodging data for inbred lines with white endosperm color are shown in table 10. These data indicate that, with further testing, they will tend to fall into high, low and intermediate groups.

The performance of the inbred lines in single crosses is shown in tables 4 to 9, inclusive, and in table 11. The results that have been obtained from single crosses involving 11 inbred lines are given in table 4. This table shows the average lodging of all of the single crosses involving these lines in five tests. The results shown in tables 5 to 9, inclusive, and table 11 represent the lodging of single crosses among inbred lines crossed in all possible combinations. Table 7 shows an average of one group for 2 years, namely, 1938 and 1939.

The relative resistance of the parental inbred lines to the southern corn rootworm is reflected in a general way in their hybrids. The single crosses involving lines resistant to the insect are more resistant than those involving susceptible lines. This is demonstrated in a comparison of tables 8 and 9. The crosses within these two groups were tested together in the same randomized blocks. Table 8 includes lines with an average lodging of 6.7 per cent and table 9 includes lines with an average lodging of 27.8 per cent. The

**Table 5.—Performance of all possible single-cross combinations among six inbred lines following attack by southern corn rootworm on the Agronomy Farm, Urbana, Ill., 1937.**

| Inbred Line Involved | Per Cent Plants Lodged 30° or More | | | | | |
|---|---|---|---|---|---|---|
| | Ia. L317 | Ind. WF9 | Ill. 5120 | Ill. Hy | Ill. R4 | In. Tr |
| Ia. L317 | — | 23.0 | 13.9 | 27.6 | 9.0 | 16.8 |
| Ind. WF9 | 23.0 | — | 14.6 | 27.8 | 36.7 | 24.0 |
| Ill. 5120 | 13.9 | 14.6 | — | 35.2 | 37.0 | 30.3 |
| Ill. Hy | 27.6 | 27.8 | 35.2 | — | 19.6 | 42.2 |
| Ill. R4 | 9.0 | 36.7 | 37.0 | 19.6 | — | 53.0 |
| Ind. Tr | 16.8 | 24.0 | 30.3 | 42.2 | 53.0 | — |
| Average lodging of single crosses | 18.1 | 25.2 | 26.2 | 30.5 | 31.1 | 33.3 |
| Average lodging of inbred lines as such in field | 23.9 | — | 14.9 | 0.0 | 17.5 | 41.7 |

**Table 6.—Performance of single cross combinations among 18 inbred lines following attack by southern corn rootworm. Pana, Ill., 1938.**

| Inbred Line Involved | Ind. 38-11 | Ind. WF9 | Iowa L317 | Ill. Hy | Oh. 56 | U. S. 187-2 | Oh. 07 | U. S. 540 | Average Single Crosses | Lodging Inbred Lines as Such in the Field |
|---|---|---|---|---|---|---|---|---|---|---|
| | Per Cent of Plants Lodged 30 Degrees or More | | | | | | | | | |
| Ind. 38-11 | — | 100. | 40.6 | 42.3 | 46.7 | 73.3 | 65.5 | 74.2 | 63.2 | 0.0 |
| Ind. WF9 | 100. | — | 71.9 | 55.2 | 50.0 | 90.5 | 83.3 | 74.2 | 74.7 | 66.7 |
| Ia. L317 | 40.6 | 71.9 | — | 87.5 | 93.8 | 93.8 | 76.9 | 100. | 75.0 | 95.8 |
| Ill. Hy | 42.3 | 55.2 | 87.5 | — | 86.7 | 64.3 | 100. | 86.7 | 76.9 | 68.0 |
| Oh. 56 | 46.7 | 50.0 | 93.8 | 86.7 | — | 67.9 | 92.9 | 100. | 80.6 | 100. |
| U. S. 187-2 | 73.3 | 90.5 | 93.8 | 64.3 | 67.9 | — | 84.6 | 100. | 82.1 | 70.4 |
| Oh. 07 | 65.5 | 83.3 | 76.9 | 100. | 92.9 | 84.6 | — | 100. | 86.2 | 89.7 |
| U. S. 540 | 74.2 | 74.2 | 100. | 86.7 | 100. | 100. | 100. | — | 90.7 | 100. |
| Oh. 28 | 6.3 | 18.2 | 56.7 | 56.7 | 96.9 | 78.1 | 88.9 | 74.2 | 59.5 | 74.2 |
| Kan. Kys | 33.3 | 38.5 | 34.6 | 67.9 | 71.4 | 92.9 | 50.0 | 93.8 | 60.3 | 48.3 |
| Ia. I205 | 35.7 | 35.7 | 75.0 | 69.2 | 56.3 | 73.1 | 92.0 | 93.3 | 66.3 | 30.0 |
| Oh. 15-6 | 50.0 | 62.5 | 17.9 | 58.6 | 89.7 | 81.3 | 85.2 | 92.6 | 67.2 | — |
| Ill. 5120 | 55.2 | 44.4 | 43.3 | 84.0 | 86.2 | 58.6 | 96.7 | 71.9 | 67.5 | 62.1 |
| Oh. 67 | 31.3 | 50.0 | 75.0 | 65.4 | 96.6 | 75.9 | 100. | 100. | 74.3 | 35.7 |
| Kan. K166 | 12.5 | 81.8 | 68.8 | 100. | 73.3 | 89.7 | 100. | 100. | 78.3 | 54.5 |
| Ill. R4 | 93.8 | 60.7 | 78.6 | 84.6 | 89.7 | 90.0 | 64.5 | 93.8 | 82.0 | 93.3 |
| U. S. 4-8 | 69.0 | 61.3 | 93.3 | 92.9 | 90.3 | 80.6 | 90.6 | 93.8 | 84.0 | 95.7 |
| Oh. 02 | 71.0 | 80.0 | 58.3 | 93.1 | 100. | 100. | 100. | 96.9 | 87.4 | 86.7 |
| Average | 53.0 | 62.2 | 68.6 | 76.2 | 81.7 | 82.0 | 86.5 | 90.9 | | |

**Table 7.—Performance of all possible single-cross combinations among six inbred lines following attack by southern corn rootworm at McClure, Ill. Average 1938 and 1939.**

| Inbred Line Involved | Per Cent Plants Lodged 30° or More | | | | | |
|---|---|---|---|---|---|---|
| | Ind. 38-11 | U. S. 540 | Ind. WF9 | Ill. Hy | Ia. L317 | Ill. R4 |
| Ind. 38-11 | — | 20.8 | 21.7 | 43.4 | 33.6 | 29.9 |
| U. S. 540 | 20.8 | — | 30.1 | 26.1 | 46.0 | 28.3 |
| Ind. WF9 | 21.7 | 30.1 | — | 51.1 | 42.3 | 58.1 |
| Ill. Hy | 43.4 | 26.1 | 51.1 | — | 50.9 | 55.9 |
| Ia. L317 | 33.6 | 46.0 | 42.3 | 50.9 | — | 56.4 |
| Ill. R4 | 29.9 | 28.3 | 58.1 | 55.9 | 56.4 | — |
| Average lodging of single crosses | 29.9 | 30.3 | 40.7 | 45.5 | 45.8 | 45.8 |
| Average lodging of inbred lines as such in field | 12.0 | 8.0 | 31.8 | 28.7 | 34.3 | 37.5 |

average lodging of the single crosses of these two groups of lines is 8.6 per cent and 44.8 per cent, respectively. Lines Ill. Hy. and Ind. WF9 are included in both groups and permit an additional comparison between the two groups.

**Table 8.—Performance of all possible single-cross combinations among six inbred lines following attack by southern corn rootworm at McClure, Ill., 1939.**

| Inbred Line Involved | Per Cent Plants Lodged 30° or More | | | | | |
|---|---|---|---|---|---|---|
| | Ind. 38-11 | Ia. L317 | Ill. Hy | U. S. 540 | U. S. 187-2 | Ind. WF9 |
| Ind. 38-11 | — | 0.0 | 2.3 | 0.5 | 1.5 | 0.5 |
| Ia. L317 | 0.0 | — | 6.7 | 5.2 | 4.4 | 17.4 |
| Ill. Hy | 2.3 | 6.7 | — | 8.7 | 2.5 | 18.3 |
| U. S. 540 | 0.5 | 5.2 | 8.7 | — | 22.2 | 14.9 |
| U. S. 187-2 | 1.5 | 4.4 | 2.5 | 22.2 | — | 24.4 |
| Ind. WF9 | 0.5 | 17.4 | 18.3 | 14.9 | 24.4 | — |
| Average lodging of single crosses | 1.0 | 6.7 | 7.7 | 10.4 | 11.0 | 15.1 |
| Average lodging of inbred lines as such in field | 0.0 | 7.7 | 1.3 | 0.0 | 7.4 | 23.6 |

**Table 9.—Performance of all possible single-cross combinations among seven inbred lines following attack by southern corn rootworm at McClure, Ill., 1939.**

| Inbred Line Involved | Per Cent Plants Lodged 30° or More | | | | | | |
|---|---|---|---|---|---|---|---|
| | Ill. Hy | Oh. 40B | U. S. 4-8 | Oh. 02 | Ind. WF9 | Ill. 90 | Oh. 51 |
| Ill. Hy | — | 21.4 | 25.0 | 20.5 | 18.3 | 44.9 | 66.2 |
| Oh. 40B | 21.4 | — | 31.4 | 30.0 | 36.5 | 55.1 | 51.8 |
| U. S. 4-8 | 25.0 | 31.4 | — | 14.5 | 39.3 | 62.9 | 57.5 |
| Oh. 02 | 20.5 | 30.0 | 14.5 | — | 60.1 | 62.6 | 65.0 |
| Ind. WF9 | 18.3 | 36.5 | 39.3 | 60.1 | — | 62.5 | 52.3 |
| Ill. 90 | 44.9 | 55.1 | 62.9 | 62.6 | 62.5 | — | 62.9 |
| Oh. 51 | 66.2 | 51.8 | 57.5 | 65.0 | 52.3 | 62.9 | — |
| Average lodging of single crosses | 32.7 | 37.7 | 38.4 | 42.1 | 44.8 | 58.5 | 59.3 |
| Average lodging of inbred lines as such in field | 1.3 | 44.2 | 0.0 | 30.3 | 23.6 | 15.6 | 79.9 |

SUMMARY.—The southern corn rootworm, *Diabrotica duodecimpunctata* F., is responsible for much lodging in corn fields throughout the Corn Belt. This injury has been recognized since 1892.

**Table 10.—Differential lodging of inbred lines with white endosperm color following attack by the southern corn rootworm.**

| Inbred Line | Per Cent Plants Lodged 30° or More | | |
|---|---|---|---|
| | Urbana[1] 1938 | McClure 1938 | McClure 1939 |
| Ky. 13 | 0.0 | | 12.4 |
| U. S. 11b | 0.9 | 31.1 | |
| U. S. 11a | 3.0 | | 0.0 |
| Ill. 5968 | 7.4 | 22.8 | 0.0 |
| Ill. 5969 | 15.0 | | |
| Ky. 30A | 17.9 | 9.8 | |
| U. S. 23 | 23.4 | | |
| U. S. 61 | 23.5 | | 7.1 |
| Mo. B103 | 24.3 | 0.0 | 5.8 |
| Ky. 27 | 25.0 | 23.6 | 4.1 |
| Ky. 89 | 30.0 | | |
| U. S. 62 | 47.8 | | |
| Ind. 33-16 | 51.0 | 20.7 | 5.3 |
| Kan. K22 | 51.0 | 70.5 | |
| Ky. 21 | 53.6 | 16.7 | 7.5 |
| Ky. 122 | 55.0 | | |
| U. S. 41 | 68.1 | | |
| U. S. 24 | 69.8 | | 7.1 |
| Ky. 73 | 70.0 | | |
| Ky. 50 | 71.4 | 86.2 | |
| U. S. 43 | 74.6 | | |
| Ky. | 77.3 | | |
| Kan. K6 | 77.5 | 73.5 | |
| Ky. 2075 | 79.2 | 82.0 | |
| Ky. 39 | 97.2 | 100.0 | 48.1 |
| Ky. 36 | 100.0 | | |
| Ky. 24 | 100.0 | | |
| Ky. 28 | 100.0 | | |
| Kan. PS4 | | | 0.0 |

[1] Data obtained from the white corn breeding nursery of W. H. Freeman, Special Research Assistant in Plant Genetics of the Illinois Agricultural Experiment Station.

**Table 11.—Performance of all possible single-cross combinations among six inbred lines following attack by southern corn rootworm at McClure, Ill., 1939.**

| Inbred Line Involved | Per Cent Plants Lodged 30° or More | | | | | |
|---|---|---|---|---|---|---|
| | Ky. 27 | Ind. 33-16 | Ky. 21 | U. S. 11a | Mo. B103 | Ill. 5968 |
| Ky. 27 | — | 4.9 | 1.0 | 13.1 | 6.8 | 6.0 |
| Ind. 33-16 | 4.9 | — | 12.6 | 9.7 | 3.5 | 19.5 |
| Ky. 21 | 1.0 | 12.6 | — | 19.2 | 35.7 | 18.3 |
| U. S. 11a | 13.1 | 9.7 | 19.2 | — | 28.7 | 38.2 |
| Mo. B103 | 6.8 | 3.5 | 35.7 | 28.7 | — | 44.7 |
| Ill. 5968 | 6.0 | 19.5 | 18.3 | 38.2 | 44.7 | — |
| Average lodging of single crosses | 6.4 | 10.1 | 17.4 | 21.8 | 23.9 | 25.3 |
| Average lodging of inbred lines as such in field | 4.1 | 5.3 | 7.5 | 0.0 | 5.8 | 0.0 |

Damage occurs after the plants are advanced in growth and is characterized by pruning and tunneling of the roots.

Data obtained show that infestation by the southern corn rootworm caused increases in lodging of the plants, in the moisture content of the ears at harvest, and in the proportion of poorly filled ears and unsound corn. Pollination may be affected adversely by lodging occurring at tasseling time.

The resistance of corn strains to larval attack was measured in these experiments by their resistance to root lodging on soil known to be infested with the insects. Data on lodging were obtained on inbred lines and single crosses during a three-year period in several localities in Illinois. The data indicate a differential response of the plants to larval attack. The Indiana inbred line 38-11, was outstanding in its resistance to lodging following rootworm attack either as an inbred line or in hybrid combinations.

Some inbred lines suffered markedly less leaf injury from the feeding activity of the adult insects than other lines grown in the same experiment.

The resistance to the injury caused by the southern corn rootworm is shown to be heritable. The development and use of resistant strains appears to be the only practical method of reducing the damage. —6-30-41.

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# Quantitative Dietary Studies on *Phymata*[1]

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The predatory bug, *Phymata pennsylvanica americana* Melin, lends itself well to research on the principles of nymphal growth and adult life as these are affected by quantitatively differentiated rates of feeding. It is common, large and phlegmatic, hence is collected, handled, weighed and dissected with ease, and thrives on the easily-cultured *Drosophila melanogaster* and *Musca domestica*.

Procedure.—The results reported here have been obtained from several series of

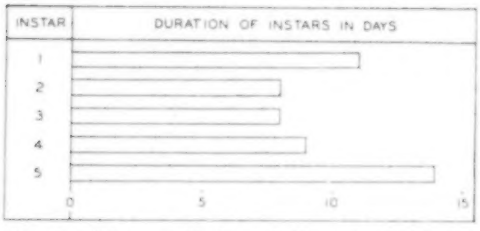


Fig. 1.—Diet and lifetime of *Phymata*. Series G.

*Phymata* reared from over-wintered eggs and from adults collected in the field. Divided into series and caged individually, the bugs from both sources were placed on a fixed schedule of daily feeding designed to produce a maximum spread in their development and life. By weighing lots of whole flies and sucked-out flies, the average adult Musca was found to contain approximately as much ingestible substance as 17 Drosophila flies. The quantity of food utilized by the bug was therefore measurable to a fair degree of accuracy. The bugs of the "less-than-optimum-fed" series mostly removed all the liquifiable substances from the captured flies. When not thus completely drained out, the per cent of matter removed was estimated by crushing the discarded flies on paper within the 24-hour period following feeding.

Humidity and temperature in the cages were not kept at a constant level during the experiment, but since these factors were alike for all bugs alive at any given time, they played a negligible part in producing the differential effects to be noted below. Room temperatures ranged from 70 to 95 Fahr., but humidity was kept above the dry indoor level. Weights cited were obtained by means of a *Chainomatic* scale accurate to one ten-thousandth of a gram. The essential data presented in tables 1 and 2 represent summaries of extensive day-by-day records. Some of these data are also expressed graphically in figures 1 and 2.

Measures of Dietary Effects.—Several kinds of concrete results were obtained from this study. These may be regarded as measures or criteria of the quantitative effects produced on the experimental bugs by the differentiated diets imposed. For the nymphs these measures are (1) the number of individuals surviving from instar to instar, and (2) the duration in days, or rate of growth, both in the several instars and in the nymphal period as a whole (Table 1). For the adults, available measures are (1) body weights, (2) body lengths, (3) longevity, (4) extent of sexual activity, *i.e.*, coupling and mating, and (5) number of

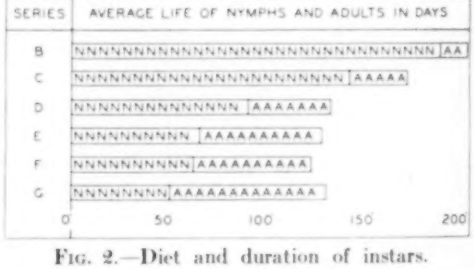


Fig. 2.—Diet and duration of instars.

eggs secured by deposition and by post-mortem dissections.

Results.—That diet exerts a striking effect on the growth and life of insects may be safely assumed from common experience with vertebrates. But the nature and extent of that effect can be learned only from experimentation. The most obvious result of the present dietary experiment is the general fact that the average survival and rate of development of the nymphs, and the average longevity,

[1] Hemiptera, Phymatidae.

[2] Contribution No. 222 from the Entomological Laboratories of the University of Illinois.

This investigation received financial support from the Research Board of the Graduate School, University of Illinois. James Slater assisted with the routine work.

**Table 1.—Diet and Nymphal Growth. Series A–G.**

| Series | First Instar | | | | Second Instar | | | | Third Instar | | | | Fourth Instar | | | | Fifth Instar | | | | Nymphal Stage | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Diet* | Nymphs reared | Duration Days ♂/♀ | Flies S. O. Total ♂/♀ | Diet | Nymphs reared | Duration Days ♂/♀ | Flies S. O. Total ♂/♀ | Diet | Nymphs reared | Duration Days ♂/♀ | Flies S. O. Total ♂/♀ | Diet | Nymphs reared | Duration Days ♂/♀ | Flies S. O. Total ♂/♀ | Diet | Nymphs reared | Duration Days ♂/♀ | Flies S. O. Total ♂/♀ | Adults reared | Average duration | Average Flies Sucked out per Bug |
| A | 1 in 12 days | 1 | 33 — — | 3 — — | 1 in 10 days | 0 | 0 — 0 | 0 — 0 | 1 in 8 days | 0 | 0 — 0 | 0 — 0 | 1 in 6 days | 0 | 0 — 0 | 0 — 0 | 1 in 4 days | 0 | 0 — 0 | 0 — 0 | None | — | — |
| B | 1 in 9 days | 16 | 25 — 13 | 3 — 4 | 1 in 9 days | 15 | 31 — 17 | 4 — 6 | 1 in 6 days | 13 | 35 — 19 | 6 — 9 | 1 in 3 days | 7 | 60 — 32 | 18 — 28 | 1 per day | 2 | 36 — 19 | 35 — 52 | ♂—0 ♀—1 T—2 | 187 days | 66 |
| C | 1 in 6 days | 16 | 21 — 15 | 4 — 6 | 1 in 6 days | 16 | 23 — 17 | 4 — 6 | 1 in 4 days | 16 | 27 — 19 | 6.7 — 10 | 1 in 2 days | 16 | 28 — 20 | 14 — 21 | 1 per day | 13 | 40 — 29 | 37 — 56 | ♂—3 ♀—8 T—13 | 140 days | 67 |
| D | 1 in 4 days | 14 | 17 — 19 | 5 — 6 | 1 in 4 days | 13 | 16 — 18 | 4 — 5 | 1 in 2 days | 13 | 14 — 17 | 7.3 — 9 | 1 per day | 13 | 19 — 21 | 18 — 23 | 2 per day | 13 | 23 — 25 | 44 — 55 | ♂—5 ♀—5 T—12 | 90 days | 78 |
| E | 1 in 2 days | 18 | 14 — 22 | 6 — 4 | 1 in 2 days | 18 | 10 — 15 | 5 — 4 | 1 per day | 18 | 10 — 15 | 10 — 8 | 2 per day | 18 | 12 — 18 | 23 — 19 | 4 per day | 18 | 20 — 30 | 76 — 63 | ♂—6 ♀—7 T—18 | 66 days | 120 |
| F | 1 per day | 18 | 14 — 25 | 7 — 3 | 1 per day | 18 | 9 — 16 | 8 — 3 | 4 per day | 18 | 9 — 15 | 29 — 11 | 8 per day | 17 | 9 — 16 | 61 — 24 | 16 per day | 16 | 16 — 28 | 147 — 57 | ♂—4 ♀—8 T—16 | 59 days | 252 |
| G | 2 per day | 18 | 11 — 23 | 13 — 2 | 4 per day | 18 | 8 — 16 | 20 — 3 | 8 per day | 17 | 8 — 15 | 37 — 7 | 16 per day | 17 | 9 — 19 | 133 — 24 | 32 per day | 17 | 14 — 27 | 338 — 61 | ♂—8 ♀—7 T—17 | 50 days | 541 |

* Diet expressed in terms of Drosophila.
T = total, including bugs died molting.

**Table 2.—Diet and Adult Life. Series A–G.**

| Series | Adults Studied | | Average Duration of Adult Life-Days | | | Diet per Bug | Average Number of Drosophilas Sucked Out | | Coupling and Mating | Mature Eggs Produced | | | | Average Length of Body in Millimeters | | Average Weight per Bug, in Grams | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | ♂ + ♀ | | Total number per bug | Number per bug per day (♂ + ♀) | | No. laid | Post-mortem eggs | Total produced | Average number per bug | Male | Female | Male | Female |
| A | None | None | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| B | None | 1 | — | 15 | — | 1 per day | 7.0 | 0.46 | — | 0.0 | 0.0 | 0.0 | 0.0 | — | 7.6 | — | 0.0089 |
| C | 3 | 8 | 35.0 | 19.0 | 23.45 | 1 per day | *21.2*<br>♂—30.8<br>♀—17.4 | 0.90 | None | 0.0 | 0.0 | 0.0 | 0.0 | 7.7 | 8.2 | 0.0135 | 0.0134 |
| D | 5 | 4 | 41.4 | 43.7 | 42.4 | 2 per day | *86.68*<br>♂—74.4<br>♀—95.5 | 2.04 | None Observed | 0.0 | 0.0 | 0.0 | 0.0 | 8.25 | 9.02 | 0.0164 | 0.0184 |
| E | 6 | 6 | 66.1 | 54.5 | 60.3 | 4 per day | *248.0*<br>♂—269<br>♀—225 | 4.11 | Both Rare | 0.0 | 4.0<br>From 2 ♀ ♀ | 4.0 | 2.0 | 8.87 | 9.42 | 0.0234 | 0.0430 |
| F | 4 | 8 | 74.0 | 51.0 | 58.6 | 16 per day | *641.4*<br>♂—744<br>♀—590 | 10.93 | Both Common | 118.0 | *116.0*<br>From 8 ♀ ♀ | 284.0 | 35.5 | 8.95 | 10.27 | 0.0252 | 0.0609 (one bug) |
| G | 8 | 7 | 61.5 | 76.1 | 68.3 | 32 per day | *1081.4*<br>♂—692<br>♀—1525 | 15.82 | Both Common | 554.0 | *108.0*<br>From 5 ♀ ♀ | 662 | 109.71 (weighted average) | 9.17 | 10.80 | 0.0279 | 0.0602 |

weight, size, mating activity and sexual productiveness of the resulting adults, largely are directly proportionate to the quantity of prey allowed the species, other factors being equal. However, research now in progress begins to indicate that quality of diet significantly supplements the quantity factor in producing these differential effects.

More concretely, these tests have shown that *Phymata pennsylvanica americana* is remarkably flexible in its adjustibility to the food supply available. The extreme range of this flexibility is exhibited by the results given for series B and G (tables), B representing the least quantity of prey that enabled nymphs to complete their growth in the maximum time and to yield the smallest number of lightest, most diminutive and absolutely sterile adults obtainable under the conditions. On the other hand, the diet allowed G produced the largest, heaviest, longest-lived, most vigorous and highest-yielding adults in the minimum time possible to the species under prevailing conditions. In the course of its combined nymphal and adult life, the average bug of low-fed series B, regardless of sex, ingested a total of 0.0246 gram of prey food, while the average optimally fed bug of series G consumed 0.7356 gram, or about 30 times the quantity allowed to series B. For the intervening series C to G, the corresponding weights of matter sucked from the Drosophilas and Muscas were 0.0288, 0.0624, 0.1224 and 0.2970 gram, respectively.

Summing up briefly the results given by the above extreme series, I find (1) that the average optimum-fed G bugs sucked out 8.2 times more Drosophilas or Musca equivalent as nymphs and 218 times more as adult females than did the bugs of the threshold series B; (2) that 7.5 times more of the optimum-fed nymphs became adults, (3) that these required only about one-third as much time for development, (4) that females lived five times longer, (5) measured one-third larger and (6) weighed 6.8 times heavier than the single female of the minimum-fed series (figure 1).

A relationship between diet and *Phymata* life similar in kind to that described above for series B to G was reflected also by forty wild females taken from the field soon after they became adults. Divided into four series of ten bugs each, all received a diet of one Musca per day for 11 days. This was done with the thought that uniform feeding would tend to cancel out the individual differences which had appeared in them during the nymphal life in nature. Thereafter, series I was allowed three Muscas per day, series II one Musca per day, III a Musca in four days and IV one fly each eighth day. Although distinct, the effects of these diets on longevity, bodily weight and egg production were less extreme than those reported for reared series B to G (tables), in which both adults and nymphs were reared on measured amounts of prey. During the period of differentiated diets, the four series sucked out an estimated average of 1.5, 0.75, 0.25 and 0.12 Muscas per day, respectively, lived averages of 55.7, 60.9, 55.8 and 29.2 days per bug, and produced average totals per series of 589, 461, 159 and 139 eggs. Compared with reared series A to G, these results strongly suggest that not only the amount of food available to the mature bugs, but also the quantity secured by the developing nymphs plays a major part in determining their longevity, weight, size and sexual productivity.

REARED AND FIELD BUGS COMPARED.—Extensive observations in the field indicate that adults underdeveloped to the extent of B series bugs rarely occur in nature. On the other extreme, 479 adult wild bugs contained no males nor females that quite equalled in weight the heaviest bugs reared in G. The heaviest six field males ranged from 0.0297 to 0.0325 gram as compared with 0.0326 grams for the heaviest male of series G, while the corresponding weights of the four heaviest field females ranged from 0.0618 to 0.0682 gram as compared with 0.0724 gram for the heaviest female of series G. These top weights characterized the field adults from late July to early September when the species was at its reproductive peak. Moreover, the G bugs are also slightly larger than the biggest young adults from the field, the males and females averaging 9.17 and 10.8 mm. in length, as compared with averages of 8.9 and 10.4 mm. respectively, for the wild series. These data tell us that the optimal dietary and climatic conditions in nature are not quite as favorable for *Phymata* life as those maintained in captivity.

The amount of prey taken by *Phymata* in nature can be inferred approximately by comparing weights of wild bugs with those of the reared series whose dietary intake was learned experimentally. On this basis the majority of field *Phymata* probably sucked out the approximate equivalent of 368 to 1622 Drosophilas in the course of their combined nymphal and adult life. The above figures pertain to the better-fed series, E, F and G (tables). Such field bugs should therefore live as long, be as large and heavy, and produce as many eggs as recorded for these series in table 2. However, the lower-weight field bugs are most nearly equivalent to those of series D, in which small, weak and completely sterile adults were produced. It seems, therefore, that some adults in nature actually live on a purely somatic level and lack the capacity to reproduce because they are underfed as adults or nymphs, or both. Concretely, in reared series B to G (tables), the rate of egg production increased from 0 in B, C and D to an average of 2.0, 35 and 100 eggs per female in E, F and G, so far as postmortem examinations were made.

FEEDING CAPACITY.—Because series G (tables) was given all the flies it was able to suck out, it provides a fairly accurate picture of the maximum feeding capacity of both nymphs and adults employed in this test. The average male nymph required 536.59 Drosophilas, or Musca equivalent, and the female nymph 558.59 such flies to complete its growth in the minimum period, whereas the adult male used an average of 692 Drosophilas and the female 1525 during its lifetime. This amounts to an average total of 1228.59 flies for the male and 2083.59 for the female during the combined nymphal and adult life. These Drosophilas are approximately equivalent in food quantity to 72 and 122 Muscas, respectively.

Those adults of the forty field females which received a Musca fly at intervals of 4 and 8 days were weighed before and after the time of feeding. Such weights show that the average amount of substance hungry female adults are capable of ingesting at one meal weighed 0.0060 gram. The weight of this maximum meal chances to represent approximately all the ingestible substance present in the average housefly. The thoroughly hungry female *Phymata* therefore ingests, at one feeding, a quantity of substance equivalent to approximately one-eighth of her own weight, using 0.0477 gram as a basis for calculation. This figure represents the seasonal average weight of 226 females fresh from the field. It was learned also that these 4 and 8 day-fed starved captive females lost weight during the period of low diets, hence they not only utilized all the food value of their meals but drew on the stored bodily reserves as well. They also exhibited sharp drops in egg production as compared with the better-fed series I and II. Series III experienced a per bug loss of 0.0076 gram and IV a loss of 0.0163 gram during the period of differential feeding which terminated at death, while series I lost 0.0025 and II gained 0.0025 gram per bug at the same time.

The original weights of series I to IV help to explain these discrepancies in the relation of dietary allowance and amount of weight loss sustained. The average weight of the individual bugs composing the four series was 0.0286, 0.0308, 0.0328 and 0.0296 gram, respectively. In other words, the egg yields, longevity and weights obtained in the several series were proportional to two factors: (1) the quantity of food material supplied during captivity and (2) the bodily weight or vigor the bugs constituting the four series had attained at the time they were transferred from field and placed on scheduled diets. It is noteworthy also, from data on the reared series of nymphs (tables), that liberal feeding in the early instars begets a greater capacity to feed in later stadia and in the adult stage.

DIET AND REPRODUCTIVITY.—Considering series B to G from the standpoint of diet in relation to reproductivity, they constitute two classes. The first consists of the lower-fed series B, C, and D, characterized by an entire absence of coupling, mating and egg production. Eggs were obtained neither by deposition nor by postmortem dissections. The diets allowed these series were therefore adequate only for somatic development and some degree of maintenance, and that adequacy varied directly with the amount of food provided by the schedule. The single female of B represented the bare subsistence level of somatic life, whereas the D adults, which developed no eggs, nevertheless probably approached quite close to the reproductive level, for some eggs

were produced in the next higher-fed series E. The second class embraces the better-fed series E, F and G, all of which coupled, mated and produced eggs. However, these functions varied quantitatively in direct proportion to the feeding rate. Only 4 eggs were obtained in the least-fed series E, and, moreover, these were the product of two bugs and were secured by postmortems. Four other females of E series yielded none. In other words, an average consumption of 120 and 225 Drosophilas by nymph and female adult, respectively, was barely sufficient intake of food to bring the species to the threshold of reproduction. Furthermore, this dietary would obviously not sustain the species, for the eggs were neither deposited nor fertilized. But an average ingestion of 252 and 590 Drosophilas per nymph and adult females respectively, of series F, increased the mean yield of eggs to 35.5 per bug, hence this rate of feeding presumably enables the species to maintain itself. That these females were below average in vigor is indicated by the sometimes absence of the golden frothy matrix with which optimum-fed females cover their eggs. Again, series A bugs, allowed all the prey they were able to suck out, utilized 541 and 1525 Drosophilas per nymph and adult female, respectively, and produced an average of 100.7 eggs per individual.

In general terms, these results indicate that the more nearly the amount of prey allowed meets optimum somatic requirements of the species, the greater is the per cent of ingested nutrient that becomes diverted to the reproductive function. And such diversion is initiated long before the maximum somatic development has been entirely achieved. The fact that egg production is affected so extremely by the quantity of food accessible suggests that many published egg records for captive insects probably do not represent the maximum productive capacity of the species.

It is noteworthy also that a series of females reared in 1939 on an optimum diet of *Musca* deposited an average of 235.36 eggs per bug, which far exceeds the performance of the maximum-fed series G fed largely *Drosophila* supplemented with houseflies. Certainly the latter series of 1940 was fed no less adequately, so far as quantity is concerned than the bugs of 1939. This discrepancy in performance is possibly due to (1) qualitative difference in diet, or/and (2) the existence of distinct genetic strains in the species.

DIET AND DURATION OF LIFE.—Quantity of prey sucked out affects directly also the relative duration of the nymphal and adult stages. On the most scanty rations (B series), the nymphal life was 12.5 times longer than that of the resulting single adult female, whereas optimum-fed series G exhibited a reversal to an average adult life 1.36 times longer than that of the nymph (figure 1). Moreover, series C to F arrange themselves between these extremes in direct accordance with the number of Drosophilas allowed by the schedule. In order to appreciate fully the differentiating effect of diet quantity on life, it must be recognized also that the average production of eggs ranged from 0 in B to 100.7 in G at the same time that the adult life increased from 17 days in the former to 76.1 in the latter. That is, the effect of diet, particularly as related to females, must be measured in terms of egg production plus longevity, and not by the latter alone, for the nutriment ingested expresses itself in both these features of adult life. In males, perhaps relatively little of the food taken is diverted to the production of sperms. And inasmuch as male life is no longer than female life and the male body is considerably smaller, it is not difficult to understand why males observed in the field fed only one-fourth as often and generally captured smaller prey than the females (Balduf, 1940).

DIET AND DURATION OF INSTARS.—The percentage duration of the several instars of series B to F is, of course, regulated by the diets allowed the bugs by the feeding schedule (table 1). But because the nymphs of series G were given all the Drosophilas they were disposed to ingest, the percentage values should represent approximately the ideal distribution of time, by instars, in this species. The per cents were 23, 16, 15, 19 and 27, respectively, for the five instars and these compare favorably with 23, 19, 13, 17 and 28 obtained for the series of bugs reared in 1939 (figure 2). The instars of field bugs doubtlessly depart considerably from these somewhat ideal percentages, for field studies have shown the *Phymata* population not infrequently undergoes two or three consecutive days of relative or complete fasting due to inactivation of potential prey by cool weather or, more often, by persistent

brisk southwest winds. It is probable that nymphs suffer deprivation for the further reason that their flightless state incapacitates them for free migration to more favorable feeding grounds. The instars in which such deprivations are experienced probably suffer noteworthy attenuation as a consequence. The results for series B to G afford good proof of this probability.

DIET AND RELATIVE LIFETIME OF SEXES.—In interpreting the relative longevity in males and females (table 2), the reader must be aware that nymphs and adults of both sexes were fed equal numbers of Drosophila per day. As a consequence, the normally larger and more voracious females were more undernourished and stunted in growth than the smaller and less rapacious males, in all series except optimum-fed G. To the latter an unlimited amount of prey was supplied, which permitted each sex to exhibit fully its inherent longevity. The shuttling relationship in the average durations noted in the males and females of series C to G (table 2) may be considerably linked with the relative bulks or weights of sperms and eggs and the normal differences in size and voracity of the males and females, as well as the differences in food allowed. In a series of field adults collected to obtain their weights, the greatest discrepancy between the two sexes paralleled the midseason peak of sexual productivity. This fact indicates that the female was probably utilizing a comparatively larger portion of her food for the genesis of eggs than the male expended in spermatogenesis.

DIET, SEX RATIO AND INSTAR NUMBER.—It is noteworthy that the numerical ratio of males and females obtained in the several reared series (table 2) is not correlated with amount of food administered. The food quantity factor as related to nymphs therefore seems to have no part in determining the sex of the resulting adults. Furthermore, food quantity does not affect the number of molts undergone during development. Whether fed the optimum or the minimum ration, whether the growth period was long or short, and the resulting adults large, heavy and productive, or small, light and sterile, five instars invariably composed the nymphal stage.

PRACTICAL RESULTS.—This research also revealed some principles pertinent to biological control involving predatory entomophagous insects. When not restricted to one generation per year by a diapause in the egg, as *Phymata* is, well-fed predators probably tend to produce one or more additional cycles yearly than the undernourished reproductive individuals of the same species. Such accelerated growth is attainable through the greatly abbreviated nymphal development and preoviposition periods induced by optimal diet. Moreover, the comparatively big and vigorous adults not only possess a greater capacity for destroying pest species but yield a much larger number of eggs and nymphs which result in the multiplication and acceleration of the control value of the species. On the basis of one generation per year only, the average individual male and female *Phymata* of series G destroyed the equivalent of 72 and 122 houseflies respectively.

The extreme flexibility exhibited in series B to G in respect to size and weight has significance to taxonomy and economic entomology. To the first it demonstrates again how unreliable size and weight characteristics are as criteria of species. Surely a considerable number of morphological "species" now recognized in the literature on the basis of conspicuous size differences merely represent extreme size forms resulting from inequalities of food secured during the feeding-growing stage. In research on chemical insecticides, such flexibility in size and weight of the test species might readily prejudice the results pertaining to the effectiveness of the substance tested. Lots of low-fed insects are clearly less tenacious of life than better-nourished lots, hence are probably more easily killed. If used as experimental subjects, such low vigor lots would give the false impression of satisfactory efficacy in the chemical under study, whereas more vigorous lots, developed on more adequate diets, could prove quite resistant to the same material or dilution.—7-11-41.

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# Some Biological Observations of the Adults of the Apple Maggot and the Cherry Fruitflies

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Incidental to some toxicological studies reported elsewhere (Middlekauff & Hansberry, 1941) there was an excellent opportunity to make interesting notes on the biology of the adults of the apple maggot, *Rhagoletis pomonella* (Walsh), and the cherry fruitflies, *Rhagoletis fausta* (O. S.), and *Rhagoletis cingulata* (Loew.).

Puparia were collected from infested fruit which was placed in wire bottom cages over a layer of sand. The emerging larvae pupated in the sand and were subsequently recovered by flotation in water. These puparia were then placed in refrigeration for several months. They were then removed, placed in moist sphagnum moss and kept at room temperature until emergence took place.

WEIGHTS OF 24-HOUR RHAGOLETIS ADULTS.—A necessary part of most of the toxicological investigations was the weighing on an analytical balance of a considerable number of individual flies. The general technique of Gaines, *et al.* (1937) who weighed a large number of houseflies *Musca domestica* L., was followed. It was felt that these weights presented in analyzed form would be of general interest, and possibly useful in subsequent toxicity studies, particularly if one wished to discard the extreme weights in favor of a group falling close to the mean.

It is to be regretted that less than 100 individuals of the two sexes of *Rhagoletis cingulata* and the males of *R. fausta* were weighed, but as stated above these weights were incidental to other studies. All flies were weighed to the fourth decimal place in a small weighing vial after having been kept for 24 hours after emergence. They were provided with food which consisted of 3 parts of yeast plus 7 parts of honey. Water was provided separately.

The ranges, means and standard deviations of the weights are shown in table 1 and histograms, figures 1, 2 and 3.

APHIS HONEYDEW AS FOOD FOR THE APPLE MAGGOT.—It is rather generally known to entomologists that the adults of the apple and cherry maggots will readily lap most moist or gummy substances with which they come in contact. If the adults are closely watched it can easily be seen that as they walk about over the fruit or leaves they are constantly extending the proboscis and applying the labella directly to the surface. This habit is not as indiscriminate as it may appear to the casual observer, since the proximity of food or moisture accentuates this labella-exploring habit. This behavior leads one to the obvious deduction that their chief source of food is moist or gummy exudates found in their normal environment. Such ubiquitous substances as aphis honeydew and fruit exudations are therefore logically suspect as an important source of food.

**Table 1.—Weights in grams of 24-hour adult *Rhagoletis* species.**

| SPECIES | SEX | RANGE | MEAN | STANDARD DEVIATION | NUMBER WEIGHED |
|---|---|---|---|---|---|
| *R. pomonella* | ♀ | .0017–.0110 | .0069 | .0018 | 280 |
| | ♂ | .0025–.0075 | .0046 | .0010 | 184 |
| *R. cingulata* | ♀ | .0032–.0070 | .0051 | .0008 | 65 |
| | ♂ | .0026–.0054 | .0038 | .0007 | 52 |
| *R. fausta* | ♀ | .0015–.0068 | .0041 | .0008 | 150 |
| | ♂ | .0018–.0039 | .0030 | .0005 | 56 |

Statements to the effect that the adults feed upon the above mentioned substances are relatively common and are usually based upon field observations. To determine how long the adult apple maggots could live upon aphis honeydew and water, ten 24-hour-old adults were confined in individual vials such as have previously been described (Middlekauff & Hansberry 1941) and were here provided every other day with a piece of rose leaf covered with honeydew excreted by the rose aphis, *Macrosiphum rosae* L. This piece of leaf was approximately one and one-half inches long by one-half inch wide and was clipped to a piece of cardboard to prevent smearing the vial and also to facilitate feeding. A piece or two of filter paper of similar size was clipped to the back of the cardboard to absorb excess moisture. This was changed with the rose leaf every other day. Fresh water was provided by means of a small cotton plug in the cork. Five fe-

The author is indebted to Professor Roy Hansberry under whose guidance these studies were conducted.

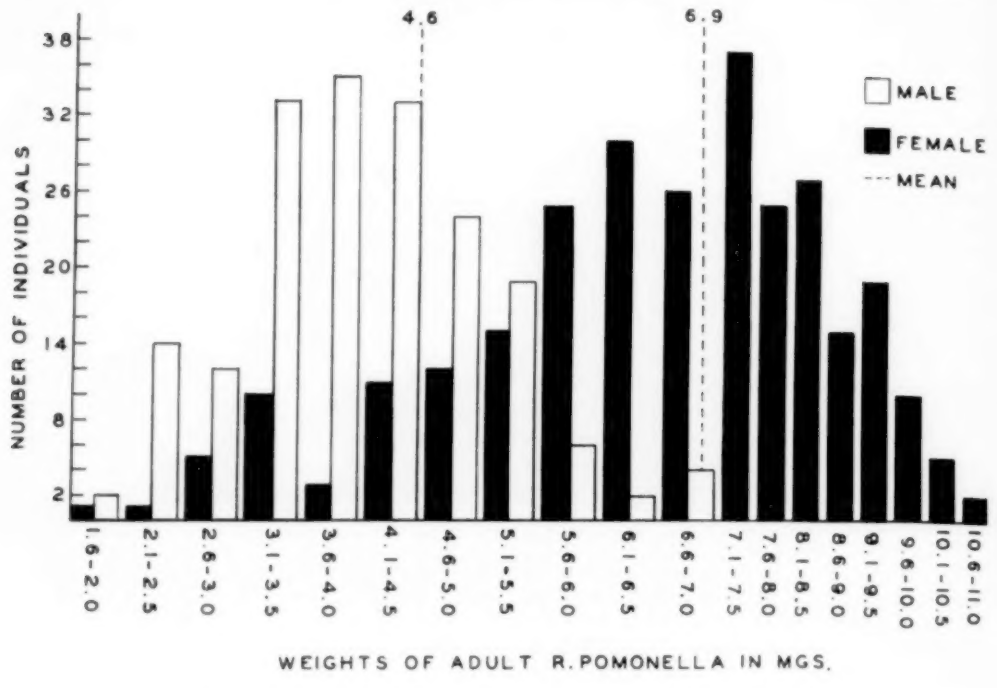


FIG. 1.—Distribution of weights of 24-hour apple maggot adults.

males survived 7, 29, 19, 25 and 28 days, respectively, with an average survival of 21.6 days. The males survived 34, 42, 24, 26 and 23 days, respectively, with an average survival of 29.8 days. Controls supplied with water alone were all dead within 5 days. Controls fed yeast and honey and held in 6 by 6 by 6-inch cages survived an average of 40 days and a maximum of 92 days. In the toxicity studies 4 days was the observation period. Since controls fed yeast and honey in individual vials lived well beyond this 4-day period no particular attempt was made to determine the maximum longevity. One small series of flies, however, did live an average of 13 days.

This experiment definitely shows that

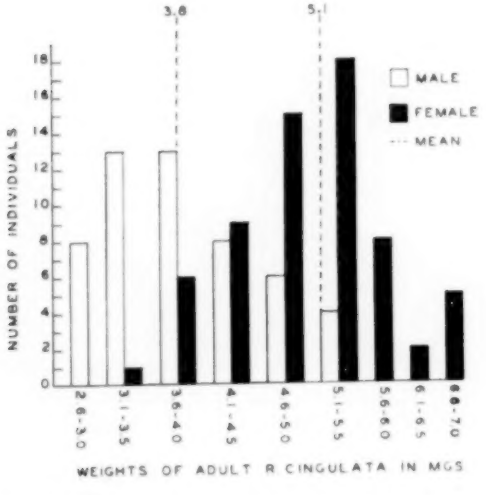


FIG. 2.—Distribution of weights of 24-hour cherry fruitfly adults.

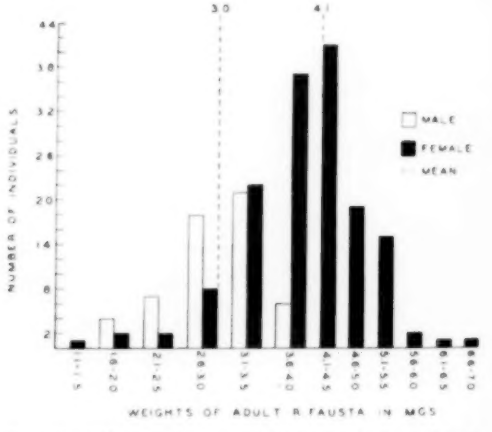


FIG. 3.—Distribution of weights of 24-hour black cherry fruitfly adults.

the adult flies are capable of living upon aphis honeydew for a considerable period of time.

PARASITES FROM RHAGOLETIS PUPARIA.[1]—The larvae of *Rhagoletis pomonella* from apples and *R. fausta* and *R. cingulata* from cherries are not heavily parasitized. From approximately 8,000 assorted puparia of the above species which were kept in moist sphagnum moss in cotton plugged flasks, less than one per cent recovery of Hymenopterous parasites was recorded over a 3-year period. Porter (1928) in speaking of *Opius ferrugineus* Gah. reports the interesting observation that the low percentage of larval parasitism of *R. pomonella* by this species may be due to the inability of the short ovipositor of the female parasite to reach the maggot larvae in the recently acquired host fruit.

The parasites which emerged from *Rhagoletis* puparia are listed according to host in table 2.

In the literature, *Opius melleus* Gah. and *O. ferrugineus* Gah. are considered to be the most important parasites of the genus *Rhagoletis*. The former is certainly of considerable importance in the bionomics of the blueberry form of the apple maggot. Lathrop & Newton (1933) reported an effective parasitism of approximately 50 per cent. It is interesting to note that in this smaller fruit the parasite is much more effective.

Three specimens of a new species belonging to the genus *Galesus* were reared from the apple maggot puparia. These were identified by Mr. C. F. W. Musebeck of the United States National Museum. Mr. Musebeck stated that this new species has previously been recorded but as yet has not been described.

TESTS FOR PRESENCE OF TARSAL CHEMORECEPTORS.—Recent authors have demonstrated the presence of chemoreceptors upon the legs of several species of adult insects. These organs perform the function of taste and enable the insect to detect the presence of food merely by walking over or in it. While it can be demonstrated that a feeding adult apple maggot will frequently place the tarsi in the liquid upon which it is feeding, it is felt that this is due more to accident or force of circumstance than to design. It has been noticed upon close observation that if the fly is at all hungry it seldom if ever walks into the liquid before sensing its presence. When a droplet of honey solution is placed upon a glass slide and inverted over the open end of a weighing vial, the enclosed fly can usually find the droplet without first touching it with the tarsi. It is not always adept at finding the food, however, for frequently a hungry fly will pass within several millimeters of some desirable food and not notice its presence until seemingly by accident it bumps into it. This inability to sense the presence of food is illustrated by tests conducted by Marshall (1933) with the adults of the apple maggot. He demonstrated that few flies were attracted to bait pans suspended in the apple tree. Frost (1929) reported from 50 to 100 *Rhagoletis cingulata* caught in syrup bait. Marshall, however, states: "The mere presence of flies in bait pans is not evidence of a response to odor. Factors such as color of pans, distance of pans from fruit, and color of liquid are all important in inciting positive responses. A white pan was found twice as good as a gray one."

To determine the presence or absence of tarsal chemoreceptors 25 adult, 24-hour unfed *Rhagoletis pomonella* were fastened to small blocks of beeswax on insect pins according to the technique used by Deonier & Richardson (1935) working

**Table 2.—Parasites from *Rhagoletis* puparia.**

| | |
|---|---|
| *R. cingulata:* | |
| *Braconidae* | |
| *Opius ferrugineus* Gah. | 14 specimens |
| *R. fausta:* | |
| *Braconidae* | |
| *Opius* sp. (*lectus-lectoides* complex) | 2 specimens |
| *Chalcididae* | |
| (*Pachycrepoideus dubius* Ashm.) | 1 specimen |
| *Cynipoidea* | |
| *Eucoila* sp. | 1 specimen |
| *R. pomonella:* | |
| *Braconidae* | |
| *Opius lectus* Gah. | 19 specimens |
| *Opius ferrugineus* Gah. | 1 specimen |
| *Aphaereta muscae* Ashm. | 2 specimens |
| *Diapriidae* | |
| *Galesus* sp. (undescribed) | 3 specimens |
| *Eulophidae* (One specimen broken in transit) | |

[1] The author wishes to thank Mr. C. F. Musebeck, Mr. A. B. Gahan and Mr. L. H. Weld for their prompt identification of parasites.

with the housefly *Musca domestica* L. They found that touching a small droplet of sucrose to the fore tarsi of the housefly would cause the fly to extend the proboscis and concluded from this response the presence of tarsal chemoreceptors.

Theoretically, if chemoreceptors are present on the tarsi any desirable food will incite a positive response. For this reason the author decided to use a 10 per cent honey solution instead of sucrose, experimental feedings having demonstrated the palatability of this substance to *Rhagoletis* adults.

Under a binocular microscope, a droplet of this solution was touched to the fore tarsi of the above 25 apple maggot adults. No positive response such as the extension of the proboscis, as reported for *M. domestica*, could be noted.

However, if the droplet was allowed to touch the labella the fly would eagerly extend the proboscis and rapidly wave the fore tarsi. The writer, therefore, finds in these limited data presumptive evidence that tarsal chemoreceptors are not present or, if present, are in insufficient numbers or effectiveness to be useful in detecting the presence of food.

SUMMARY.—The weights of 787 adult *Rhagoletis* sp. are given and the means may be summarized as follows: *R. pomonella* ♀♀ .0069 g., ♂♂ .0046 g.; *R. cingulata* ♀♀ .0051 g., ♂♂ .0038 g.; *R. fausta* ♀♀ .0041 g., ♂♂ .0030 g. All flies were 24 hours old when weighed and had been provided with food and water during this holding period.

Ten adult apple maggots were confined in individual vials and supplied with rose leaves covered with honeydew excreted by the rose aphid, *Macrosiphum rosae* L. Fresh water was provided through a cotton plug in the perforated cork. The leaves were changed every other day. The number of flies was limited by the availability of aphis honeydew. The mean survival time was 26.1 days. Starvation checks were mostly dead within four days with a few surviving five days.

The following hymenopterous parasites are recorded from *Rhagoletis* puparia: *R. pomonella*, *Opius lectus* Gah., *Opius ferrugineus*, Gah., *Aphaereta muscae* Ashm., *Galesus* n. sp., *Eulophidae* sp.; *R. cingulata*, *Opius ferrugineus* Gah., *R. fausta*, *Opius* sp. (*lectus-lectoides* complex), *Pachycrepoideus dubius* Ashm., *Eucoila* sp.

Tests for the presence of tarsal chemoreceptors using the method of Deonier & Richardson (1933) are given with negative results.—6-30-41.

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## NOTICE TO CONTRIBUTORS

Dr. R. C. Roark, of the Bureau of Entomology and Plant Quarantine, has written the editor as follows: "The word 'cube' should be written without the accent mark over the 'e.' As our authority for this form we have consulted the publication issued by the Estacion Experimental Agricola de La Molina, Lima, Peru, on 'El Cube (*Louchoca pusnicou*) y Otros Barbascos in el Peru,' by J. E. Wille, J. Alcides Ocampo, A. Weberbauer and D. Schofield (Boletin No. 11, Junio de 1937).

The *Journal* will, in the future, attempt to conform to this usage.

# Toxicological Studies with Adults of Apple Maggot and Cherry Fruitflies

WOODROW W. MIDDLEKAUFF and ROY HANSBERRY, *Cornell University, Ithaca, N. Y.*

Several types of toxicity studies are reported with the following aims in mind: To determine the comparative toxici ies of trivalent and pentavalent arsenic to the apple maggot, *Rhagoletis pomonella* (Walsh), the cherry fruitfly, *Rhagoletis cingulata* (Loew), and the dark cherry fruitfly, *Rhagoletis fausta* (O. S.). This work follows closely the method of Pearson & Richardson (1933) using the housefly. *Musca domestica* L. To study the toxicity of some nicotine compounds and Reinecke salt, using the same individual feeding method as used in the first section. To conduct cage tests with a miscellaneous group of insecticides, following the method of Boyce (1934) who worked with the walnut husk fly, *Rhagoletis completa* Cress.

MATERIALS.—Unless specifically mentioned otherwise the following materials were prepared by Dr. L. B. Norton of the New York State Experiment Station, Geneva, to whom thanks are due for this and other valued assistance in the work.

*Trisodium arsenate* and *trisodium arsenite*. Solutions of these materials had a concentration of 1.01 grams $As_2O_5$ and 1.00 gram $As_2O_3$ per 100 ml. respectively and a pH when diluted 10 times of 11.34 and 11.88 respectively.

*Reinecke salt*. Ammonium tetrathiocyanato diammino chromium $NH_4[(NH_3)_2 Cr(SCN)_4]$. $H_2O$, commonly known as Reinecke salt, was prepared from ammonium thiocyanate and ammonium dichromate according to the method of Dakin (1935).

*Nicotine alkaloid*. This material was prepared and purified from commercial 95% nicotine. At the time of preparation it possessed a specific optical rotation of 168.90 degrees which indicates practically 100 per cent purity. It was kept in the dark in sealed ampoules.

*Nicotine Reineckate*. This insoluble compound was precipitated from a solution of Reinecke salt with nicotine sulfate. It contains 31.75 per cent of nicotine.

*Nicotine bentonite*. A commercial grade (*Black leaf 155*, manufactured by the Tobacco By-Products and Chemical Corp., Louisville, Ky.) containing 5.4 per cent nicotine was used.

*Nicotine silicotungstate*. This nicotine compound was prepared by the addition of 10 per cent silicotungstic acid to a solution of nicotine acidified with HCl. The washed and dried precipitate, white in color, contained 10.12 per cent of nicotine. It is insoluble and the particles in suspension quickly settle to the bottom of the container.

*Nicotine peat*. Doctor L. N. Markwood of the Division of Insecticide Investigation, Bureau of Entomology and Plant Quarantine furnished this material compounded with New Jersey peat. It contained 10.05 per cent of nicotine.

*Arsenate of lead*. A commercial grade of Grange League Federation acid lead arsenate was used which contained 65.03 per cent PbO, 31.68 per cent $As_2O_5$, and 0.27 per cent $As_2O_3$.

*Calcium arsenate*. A commercial grade of calcium arsenate manufactured by the Niagara Sprayer and Chemical Company Inc., Middleport, N. Y., was used. It contained 42.08 per cent $As_2O_5$ and .09 per cent $As_2O_3$.

*Synthetic cryolite* (*Syncrolite*). A commercial grade manufactured by Jungmann and Company, New York, N. Y.

*Barium fluosilicate* (*Dutox*). A commercial grade manufactured by the American Fluoride Company, New York, N. Y.

*Phenothiazine* (*Thiodiphenylamine*). A commercial grade manufactured by the Dow Chemical Company, Midland, Mich.

METHODS.—The insects used in these experiments were reared in the insectary from puparia collected the preceding season. Infested fruit was placed in trays which had tops and bottoms constructed of galvanized hardware cloth. The trays were placed over a layer of sand and the larvae emerging from the fruit dropped onto the sand and there pupated. These puparia were later recovered by flotation and placed in cold storage at 35° F. Here they were kept for 2 to 3 months. They were then removed, placed in moist sphagnum moss and kept at room temperature until emergence took place. The newly

emerged flies were placed in cages, provided with food and water, and kept for 24 hours before being used in toxicity tests. The food consisted of 3 parts of bakers' yeast in 10 parts of honey with water provided separately.

The toxicity tests may be grouped under three headings as follows, based upon the compounds used and type of treatment:

1. *Comparison of trivalent and pentavalent arsenic fed in individual doses.* 376 adult flies of the three species previously mentioned were first weighed to the fourth decimal placed upon an analytical balance and were then fed varying amounts of poisons. The flies were permitted to feed by placing a droplet of the solution on a clean glass slide and inverting this over the open end of the weighing vial.

By varying the concentration and the amounts imbibed, a wide range of doses can be secured. If the fly ingests too much liquid it will often regurgitate, therefore, it is necessary so to regulate the concentration that an adequate amount of poison can be ingested before repletion. It is easy to tell when the fly is nearing repletion because the abdomen becomes greatly swollen and much lighter in color due to the exposure of the intersegmental membranes.

After feeding, the flies were reweighed and the difference in weight represented the amount of liquid consumed. From this, the dose on the basis of milligrams of As per gram of body weight could easily be calculated. These doses were used in the determination of the median lethal dosage (M. L. D.) as explained by Campbell & Filmer (1929). The flies were then placed in individual vials and there kept under observation for four days. Food in the form of 3 per cent yeast in 10 per cent honey solution was supplied daily through a perforation in the cork which was stoppered with a cotton plug. Strips of absorbent filter paper were placed in the vial and were changed daily. Adequate controls were run with a complete absence of mortality during the four day period. All flies alive at the end of this period were considered unaffected by the poisons and were released.

2. *Individual feeding studies with nicotine compounds and Reinecke salt.*

The flies in these tests were handled in a manner similar to that used in the above studies. In order to increase their palatability, some of the compounds were diluted in 10 per cent honey instead of distilled water. Insolubility or distastefulness, or a combination of the two, precluded the measurement of nicotine dosages. The flies were weighed before and after feeding, however, to ascertain whether or not they had fed.

Five nicotine compounds were fed in varying concentrations to one hundred and thirty-two adult flies.

3. *Cage Tests.* Laboratory toxicity tests were performed by the technique of Boyce (1934). Rhode Island Greening apples were first washed under two changes of tap water and then dried with clean cheese cloth. These apples were then sprayed using a *DeVilbiss* stationary gun at a constant pressure of 15 lbs. per square inch with continuous agitation of the spray mixture. The apples were sprayed on all sides until the droplets began to run. Approximately 5 ml. of solution was required for each apple. All materials were diluted in a 20 per cent sucrose solution. Controls received stock sucrose solution only, and in amounts equal to those received by other units of the series. Two apples were provided for the controls because it was found that one apple was insufficient. The flies apparently lived long enough to consume all the sucrose and then starved to death.

These apples were suspended in small, wire, sliding glass-fronted cages 6×6×6 inches in size. A constant supply of fresh water was also supplied. A circular celluloid type of cage was tried and gave very satisfactory results.

The number of flies used in each test varied with the daily emergence, but was usually from 15–50 individuals. These were confined in the cages to feed upon the treated fruit.

Materials used, their concentrations and the results are summarized in table 2. Most of the materials were used at a concentration equivalent to about three times recommended field strength.

The number of dead flies in each test was recorded twice daily, once in the morning and once in the afternoon, and these were not considered dead until all body movement had ceased.

The time-mortality lines were plotted according to the method of Bliss (1937)

with the ordinates as net percentage of mortality on the basis of probits (probability units) and the abscissas as logarithms of the time of survival after treatment. The lines were fitted by eye to the logarithm-probit points (Figs. 1–4).

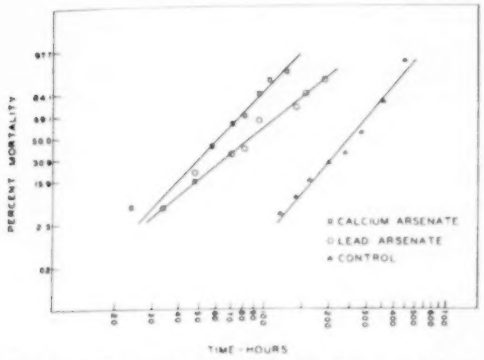


FIG. 1.—The relative toxicity of calcium and lead arsenate to the adults of *Rhagoletis fausta*.

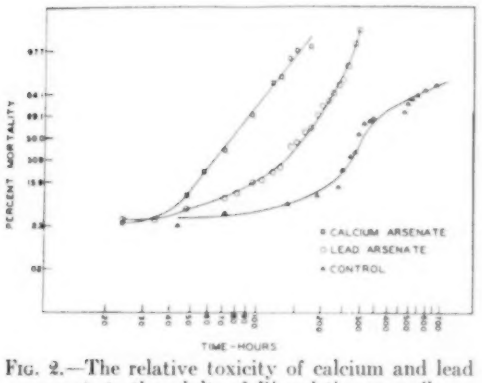


FIG. 2.—The relative toxicity of calcium and lead arsenate to the adults of *Rhagoletis pomonella*.

RESULTS.—*Comparison of trivalent and pentavalent arsenic fed in individual doses.* The results of these tests are summarized in table 1.

It is to be noted that the M. L. D. for both arsenicals is lower for the cherry fruit flies, indicating that they are more susceptible to arsenicals than is the apple maggot.

Pearson & Richardson (1933) found that with trisodium arsenite the M. L. D. for the housefly was 0.18 mg. As gram, equivalent to 0.23 mg. $As_2O_3$/gram of body weight.

*Individual feeding studies with nicotine compounds and Reinecke salt.*—*Nicotine silicotungstate* at concentrations of 48 mgs. of nicotine alkaloid per ml. of distilled water was offered to five adult apple maggots and was found to be slightly repellent. A new sample was made up using 10 per cent honey instead of water and the amount imbibed was approximately

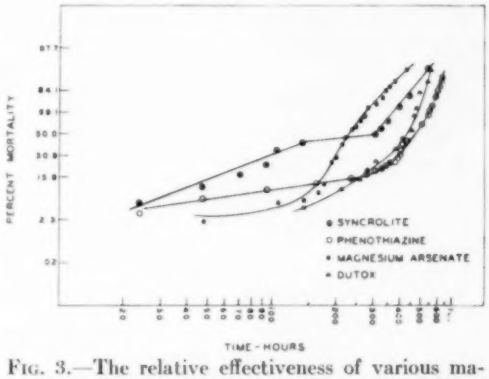


FIG. 3.—The relative effectiveness of various materials applied in the form of spray to the adults of *Rhagoletis pomonella*.

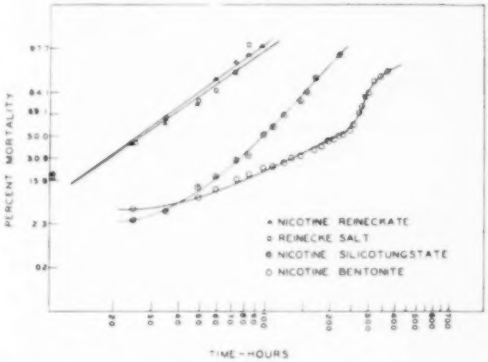


FIG. 4.—The relative effectiveness of Reinecke salt and several fixed nicotines to the adults of *Rhagoletis pomonella*.

doubled. Six flies were fed at this concentration. The concentration was then reduced to 36 mgs./ml. of 10 per cent honey and fed to three adult apple maggots and six dark cherry fruit flies. Since no repellency was noted the average weight of the liquid imbibed in this last series was .0014 g. which is a fairly large amount. No symptoms of distress were visible and no mortality during the four day observation period.

*Nicotine peat* at concentrations from 36 to 12 mgs. of alkaloid per ml. of 10 per cent honey was offered to 23 adults of the apple maggot and dark cherry fruit flies but only at the lowest concentration was it possible to feed measurable amounts to

about half of the flies. Several insects exhibited distress symptoms, but all recovered.

*Nicotine bentonite* at a concentration of .24 mg. of alkaloid per ml. of water was fed to 20 adult apple maggots. It was not repellent. Some insects gave signs of distress, but as with the above, no mortality resulted.

*Nicotine alkaloid* in concentrations from 10 to .0156 mg. of alkaloid per ml. of 10 per cent honey was fed to 42 adults of *R. pomonella*, *R. fausta*, and *R. cingulata*. It proved to be repellent even at the lowest concentration. A few flies imbibed small amounts and soon became violently ill. Regurgitation was noticed and all flies subsequently recovered.

*Nicotine Reineckate* in concentrations from 32 to .1 mg. of alkaloid per ml. of water was fed to 27 adult apple maggots. This material was not repellent and the flies fed freely. The most startling indications of distress were noticed in about 3 to 5 minutes after feeding. The first symptoms noticed were a paralysis of the hind legs, quickly followed by the fly falling upon its back and feebly twitching and waving its legs. Then the insect, as if in a sudden paroxysm of pain, would vibrate its wings and rapidly spin about the vial still remaining upside down. Regurgitation was frequently observed at this time. Every indication seemed to point towards an imminent and speedy death. Surprising as it may seem, the flies had usually recovered completely within 15 to 20 minutes. Only two flies died within the four day period.

*Reinecke salt* in aqueous solution and in varying amounts was fed to sixty-four adult apple maggots in concentrations up to 2.4 mg./ml. of water. If a lethal dose had been ingested, symptoms of extreme distress were witnessed within 3 to 5 minutes after imbibition. The initial symptoms were identical as far as could be determined, with those observed with nicotine Reineckate, with the exception, however, that only a very few recovered.

**Table 1.—The toxicity of trisodium arsenate and trisodium arsenite fed quantitatively to adult *Rhagoletis*.[1] Doses expressed as metallic arsenic.**

| Species | Arsenical | Lethal Dosage Range mg./gram | Intermediate Zone | | Sublethal Dosage Range mg./gram | M. L. D. mg./gram |
|---|---|---|---|---|---|---|
| | | | Dosage Range mg./gram | No. of Flies | | |
| *R. pomonella* | $Na_3AsO_4$ | .16–.32 | .051–.15 | 57 | .016–.048 | 0.10 |
| | $Na_3AsO_3$ | .15–.30 | .037–.14 | 68 | .007–.036 | .009 |
| *R. cingulata* | $Na_2AsO_4$ | .11–.34 | .042–.10 | 12 | –.023 | 0.08 |
| | $Na_3AsO_3$ | .09–.20 | .047–.09 | 27 | .020–.045 | 0.07 |
| *R. fausta* | $Na_3AsO_4$ | .14–.37 | .029–.12 | 37 | .006–.027 | .07 |
| | $Na_3AsO_3$ | — | — | — | — | — |

[1] Since the sexes showed no differences in susceptibility to the arsenicals they are not treated separately in the table.

Twenty-nine flies were fed doses ranging from .012 to 1.04 mgs./gram of body weight and were all dead within the four day period. Seventeen fed amounts ranging from .005 to .010 mgs./grams of body weight with ten dying and seven surviving. These constitute the intermediate zone and give a M. L. D. of .0079mg./gram of body weight. In the sub-lethal zone, eighteen fed amounts ranging from .0007 to .004 mg. per gram of body weight with all surviving.

3. *Cage Tests.*—The results of the toxicity cage tests are summarized in table 2, where the mean hours required for 50 per cent mortality is graphically shown for *R. pomonella* and *R. fausta*. In Figs. 1–4 these mortalities are plotted on the probit scale against the logarithm of the times.

The sigmoid-shaped curve of a normal time-mortality graph generally becomes a straight line when the logarithms of the times are plotted against the probits of mortalities. Theoretically then, the graphs in Figs. 1–4 should have shown straight lines. That all do not conform to the normal is readily apparent. It is interesting to note, however, that where the mean

time for 50 per cent mortality is 96 hours or less, the curves are generally normal. The remaining eight curves, including the checks, are all more or less consistent in showing a curvilinear regression. This upcurve may possibly be due to a combined low toxicity and spaced feedings.

The speed of toxic action of Reinecke salt and nicotine Reineckate to the adults of *R. pomonella* was striking. Calcium arsenate, nicotine silicotungstate, arsenate of lead, synthetic cryolite, nicotine bentonite, magnesium arsenate, phenothiazine and barium fluosilicate were effective in the order named.

Calcium arsenate also killed more quickly in tests against *R. fausta* than lead arsenate. Using speed of toxicity as the basis of comparison, *R. fausta* is much more susceptible than is the apple maggot to these two materials, as has been demonstrated with trisodium arsenite and trisodium arsenate.

CONCLUSIONS.—Tests of trisodium arsenite and trisodium arsenate against the apple maggot and the cherry fruit flies, demonstrated no differences in toxicity between the trivalent and pentavalent arsenic. The cherry fruit flies were more susceptible to poisoning by these arsenicals than were the apple maggots.

Among other materials tested nicotine Reineckate and Reinecke salt proved the most toxic. Their approximately equal effects indicated that the toxicity of nicotine Reineckate was due to the toxicity of Reinecke salt and not to nicotine. In general nicotine and its compounds were repellent to the flies and were frequently regurgitated. Violent effects which followed the feeding of the alkaloid and some of the compounds to the few individuals not repelled by them indicated a decided toxicity, however.

Nicotine compounds fed in individual doses were regurgitated more than other compounds, and may have been responsible for the ability of the flies to recover from individual feedings.

An important difference between the individual feeding tests and the cage tests lies in the fact that unpoisoned food was provided for the flies fed individually, whereas insects in the cage tests had access only to poisoned food.

Whether this difference in technique was responsible for an apparent difference in toxicity is not known.

Calcium arsenate was more rapid in its toxic action than lead arsenate against both *R. pomonella* and *R. fausta*.

Lead arsenate is generally recommended for the control of these insects. It is interesting to note that in the laboratory it takes 7 days with *R. pomonella* and 4 days with *R. fausta* to obtain 50 per cent mortality of flies confined on poisoned fruit. It is logical to assume that in the field it must take at least this long or longer to kill half of the poisoned flies. When this

Table 2.—Results of cage toxicity studies.

| Materials Used | Grams per 100 c.c. | Number Tests | Number Flies | Mean Number of Hours Required for 50% Mortality (0 50 100 150 200 250 300 350 400 450 500) |
|---|---|---|---|---|
| *Rhagoletis pomonella* | | | | |
| Sucrose (control) | 20.0 | 2 | 44 | 310 |
| Arsenate of lead | 1.0 | 4 | 124 | 165 |
| Calcium arsenate | 1.0 | 3 | 92 | 76 |
| Magnesium arsenate | 1.0 | 2 | 46 | 240 |
| Synthetic cryolite | 1.0 | 1 | 16 | 190 |
| Barium fluosilicate | 1.0 | 1 | 19 | 450 |
| Phenothizaine | 1.0 | 1 | 38 | 312 |
| Nicotine Reineckate | 0.5 | 2 | 62 | 25 |
| Reinecke salt | 0.5 | 2 | 52 | 24 |
| Nicotine silicotungstate | 1.5 | 2 | 64 | 96 |
| Nicotine bentonite | 3.0 | 2 | 60 | 215 |
| *Rhagoletis fausta* | | | | |
| Sucrose (control) | 20.0 | 1 | 25 | 250 |
| Lead arsenate | 1.0 | 1 | 20 | 90 |
| Calcium arsenate | 1.0 | 1 | 20 | 62 |

is realized, the necessity of proper timing of sprays is apparent. This slow action of the materials may be related to the ability of the flies to regurgitate toxic substances after a normally lethal dose has been ingested.

SUMMARY.—Methods of obtaining pupae, and of rearing and feeding the adults of *Rhagoletis pomonella* (Walsh), *Rhagoletis fausta* (O. S.) and *Rhagoletis cingulata* (Loew.) are described. The median lethal doses of trisodium arsenite and trisodium arsenate were calculated for these species by a technique whereby the individual flies were fed on solutions, dosage being determined by weight differences. No differences in the toxicities of trivalent and pentavalent arsenic were noted. The median lethal dose of trisodium arsenate and trisodium arsenate for the apple maggot was .10 and .09 milligram metallic As per gram of body weight respectively as compared to .08 and .07 mg./gm. for *R. cingulata*. The M. L. D. of trisodium arsenate for *R. fausta* was .07 mg. As/gm. The most toxic substance tested, Reinecke salt, gave a median lethal dose of .0079 mg./gm. Compounds of nicotine, although decidedly toxic in cage tests, were generally too repellent or too emetic in individual tests to be effective. Nicotine alkaloid was repellent at the lowest concentration used, .0156 mg./ml. No correlation between solubility of the nicotine compounds and repellency could be noted.

In laboratory cage tests, calcium arsenate always killed more quickly than lead arsenate, and again the cherry fruit flies were more susceptible to the arsenicals than was the apple maggot. Seven days were necessary to obtain 50 per cent mortality of apple maggots caged with no other food than apples sprayed with lead arsenate in 20 per cent sucrose.—5-13-41.

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# Characteristics of Different Types of Nicotine Sprays

## *I. Nicotine Residues*[1]

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Following laboratory studies on the toxicity of various nicotine compounds and oils and on the amount and permanence of their deposits on glass, the present experiment was designed to extend the tests on representative types of these materials to field conditions. The present paper deals only with the nicotine residues, and the insect control data are given in the next paper of this series. From the standpoint of residues the following information was desired: (1) the rapidity of the loss of nicotine during drying of the spray; (2) a comparison of the deposits from soluble nicotines and oil with those from "fixed" nicotines; (3) a comparison of the deposits from different types of soluble and of fixed nicotines; (4) a comparison of the deposits of soluble nicotines with mineral and with vegetable oils; (5) the effect of weather conditions upon the different types of deposit. A number of the combinations differed widely from those used in accepted commercial spray schedules, since they were chosen to represent a variety of chemical, physical, and toxicological properties rather than a group of practical spray mixtures.

EXPERIMENTAL DESIGN.—The experiment was carried out in a rectangular block of about 180 twenty-five-year-old Rhode Island Greening trees located near Interlaken, New York. Ninety-six trees from this block were selected at blossom time for probable yield, age, size, and general condition. These were divided into an

[1] Approved by the Director of the New York State Agricultural Experiment Station for publication as Journal Paper No. 471, March 15, 1941.

east, a central, and a west block, and the eight treatments assigned to four-tree plots in each block so that each treatment was applied to a total of twelve trees arranged in triplicated four-tree plots.

SPRAY SCHEDULE.—Prior to the experimental sprays, the orchard had received a delayed dormant spray of oil and nicotine sulfate, and a pink, calyx, and first cover spray of lead arsenate and lime-sulfur. Three cover sprays of the experimental materials were then applied on June 26, July 8, and July 19 for the first brood, and a fourth on August 8–9 for the second brood. The mixtures used in these four sprays are given in table 1.

Table 1.—Spray mixtures.

| | |
|---|---|
| Plot No. 1 | Petroleum oil 2 quarts, nicotine sulfate 1 pint per 100 gal. |
| Plot No. 2 | Petroleum oil 2 quarts, nicotine oleate 1.1 pint per 100 gal. |
| Plot No. 3 | Rapeseed oil 2 quarts, nicotine oleate 1.1 pint per 100 gal. |
| Plot No. 4 | Rapeseed oil 2 quarts, nicotine sulfate 1 pint per 100 gal. |
| Plot No. 5 | Rapeseed oil 2 quarts, nicotine peat 4 pounds per 100 gal. |
| Plot No. 6 | Blown rapeseed oil 1 pint, nicotine peat 4 pounds per 100 gal. |
| Plot No. 7 | Nicotine pectate 3 pints per 100 gal. |
| Plot No. 8 | *Black Leaf 155 Concentrate* 3 pounds per 100 gal. |

All the quantities of oil given refer to the actual oil, not the emulsion. All of the oils in Plots 1 to 5 were emulsified at the beginning of the season with sodium oleyl sulfate and bentonite into a stock emulsion containing 80 per cent oil. The blown rapeseed oil, however, was added to the spray tank without previous emulsification. The amounts of nicotine compounds were chosen to give approximately the same amount (0.05 per cent) of actual nicotine in each spray mixture.

The sources of the materials were as follows:

*Petroleum oil.* Shell Oil Co., light-medium horticultural spray oil; viscosity 60 sec. Saybolt at 100°F.; unsulfonated residue 92 per cent.

*Rapeseed oil.* Welch, Holme, and Clark Co., New York City.

*Blown Rapeseed oil.* Werner G. Smith Co., Cleveland, Ohio.

*Nicotine Oleate.* Prepared by adding an equivalent amount of 95 per cent nicotine to commercial oleic acid. 35 per cent nicotine.

*Nicotine Sulfate. Black Leaf 40.* Tobacco By-products and Chemical Corp., Louisville, Kentucky. 40 per cent nicotine.

*Nicotine Bentonite. Black Leaf 155 Concentrate.* Tobacco By-products and Chemical Corp. 15 per cent nicotine.

*Nicotine Pectate.* Prepared by adding an approximately equivalent amount of 95 per cent nicotine to a water suspension of pectic acid prepared by the California Fruit Growers Exchange, Ontario, California. 15 per cent nicotine. Yields a gelatinous type of deposit.

*Nicotine Peat.* Prepared by L. N. Markwood of the Division of Insecticide Investigations, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture. 10 per cent nicotine.

SAMPLING.—The size of the sample varied from twenty-five apples early in the season to eight apples at the end. Each sample was taken from a single tree, care being taken to get as representative a sample as possible, since Fahey & Rusk (1939) have shown that the variations in spray residues tend to be much greater in different parts of the same tree than between different trees given the same treatment. Three-fifths of the apples in each sample were taken from the lower part of the tree which could be reached from the ground and two-fifths from the upper branches, this being the approximate distribution of the crop as a whole. Each sample included apples from all sides of the tree and from different heights, the individual fruits being chosen at random. The sizes of the fruits were also random, although abnormally large or small apples were omitted.

Duplicate samples from different trees were taken for the first two or three determinations after each spray, when the residues were largest and most variable, and single samples for the rest of the determinations. The duplicate samples were always taken by two different people and the single samples usually taken alternately by the two, in order to minimize any personal differences in sampling technique. Successive samples were taken from different trees in different blocks, so that the final series of analyses included samples from every tree sprayed.

The first sample from each plot was taken within two or three minutes after the individual tree was sprayed, since it

was found in the laboratory that the period of drying was the period of most rapid loss of nicotine. The second was taken as soon as the spray had completely dried, giving an interval of two to five hours, depending upon the weather and the time of day. The next sample was usually taken the following day, and subsequent samples after gradually lengthening periods as the amount of residue and the rate of its disappearance became smaller.

REMOVAL OF RESIDUE.—It was necessary to strip the residues from the apples in the field as soon as the sample was collected in order to avoid serious loss of nicotine during transportation, particularly from those samples taken soon after spraying. The equipment for this purpose was set up in a small enclosed truck. The apparatus included a torsion balance for weighing the samples, large wide-mouth bottles with plastic screw caps for shaking the apples with the stripping solution, a supply of 0.5 per cent sodium hydroxide and a 100 cc. pipet for its measurement, pint fruit jars for transportation of the samples in solution, a 2-liter graduated cylinder and a metal can with a side-arm for measuring the volume of the samples by water displacement, and a supply of distilled water for washing the apparatus between samples.

The residues were stripped from the apples by a procedure similar to that of Markwood (1939). The sample was collected in the large bottle, which was capped as soon as the sample was complete in order to avoid any loss of nicotine. The bottle and sample were weighed, and the previously determined weight of the bottle deducted. One hundred cc. of the 0.5 per cent sodium hydroxide was added, and the sample shaken with the alkali for three minutes. The solution was drained from the apples as completely as possible without rinsing into a fruit jar, which was immediately sealed for transportation to the laboratory. The stripping was completed about five minutes after collection of the sample. The volume of the apples was then measured by filling the side-arm can to the point of overflowing, dropping in the whole sample of apples, holding them under the surface of the water with a disc of wire screening, and collecting and measuring the volume of displaced water in the large graduated cylinder.

NICOTINE DETERMINATION.—The nicotine in the residue was determined by the colorimetric method of Markwood with slight modifications. A 75 cc. sample was pipetted out of the stripping solution into a 100 cc. volumetric flask and clarified with bentonite and calcium acetate, using twice the amounts of these reagents specified by Markwood. In those samples containing a large amount of nicotine it was necessary to decrease the aliquot to 25 cc. and add 50 cc. of 0.5 per cent sodium hydroxide. A 75 cc. portion of this clarified and filtered solution was neutralized with acetic acid and diluted to 100 cc. The color was developed in 10 cc. of this solution with 2 cc. of cyanogen bromide and 10 cc. of alcoholic $\beta$-naphthylamine. The depth of color was determined in an *Evelyn* type photoelectric colorimeter with a *Corning* #47 light filter. It was found that the blank was quite variable because of the fact that it was not possible to remove with the bentonite all of the coloring materials taken from the apples, particularly early in the season. Accordingly, a blank determination for each sample was run along with each analysis. The blank was run in exactly the same way as the determination with the substitution of 2 cc. of distilled water for the cyanogen bromide. A correction was then made for the blank.

CALCULATIONS.—In view of the variability of the blank, a graphical estimation of the amount of nicotine from the colorimeter reading would require a separate curve for each blank. The concentration of nicotine, however, varies with the logarithm of the colorimeter reading, so that an equation can be derived for the family of curves with varying blanks. The equation used for the calculations with the particular conditions and apparatus of these experiments was as follows:

$$C = 0.0268 \log (\text{Blank}/\text{Reading})$$

where C represents the milligrams of nicotine per cc. of the unknown solution, and Blank and Reading represent the colorimeter readings for the unknown solution with water and with cyanogen bromide respectively. The total amount of nicotine in the original apple sample was then 178 C mg. where a 75 cc. aliquot was taken and 533 C mg. for a 25 cc. aliquot.

The total surface area of each sample,

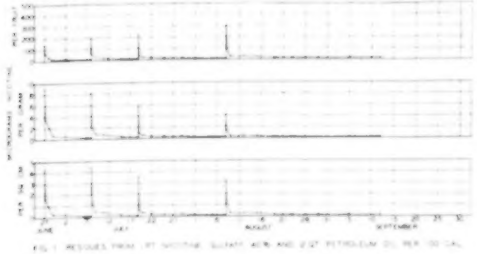
assuming the apples to be perfect spheres, was calculated from the total volume by the formula:

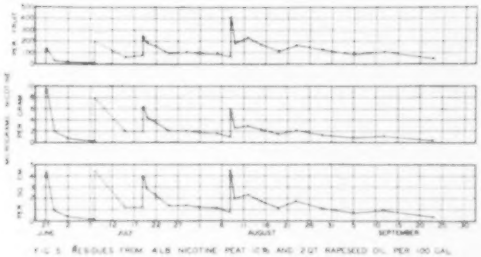
$$A = 4.84\ V^{2/3}\ N^{1/3}$$

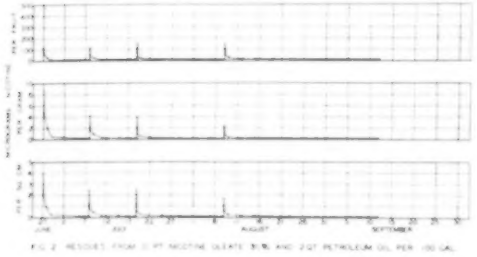
where A is the total area in square centimeters, V the total volume in cubic centimeters, and N the number of apples.

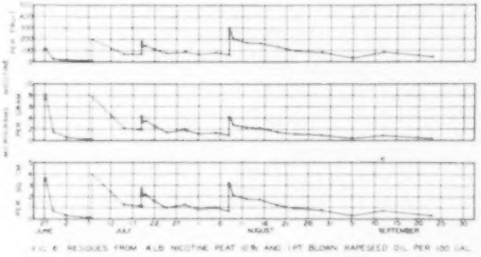
The nicotine residues were then calculated on the basis of three different measures of the sample: number of fruits, weight of fruit, and surface area.

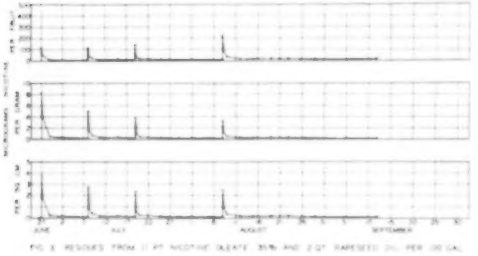
ERRORS. The greatest source of error lies in the sampling, and not in the analysis. The difference between duplicates was in most cases far greater than the analytical error. In those cases where an analysis appeared distinctly out of line, investigation usually showed that the sample was of a different size from the others of the same group, either because of a difference in the crop on the individual tree or because of personal differences in sampling. It was felt, however, that random sam-

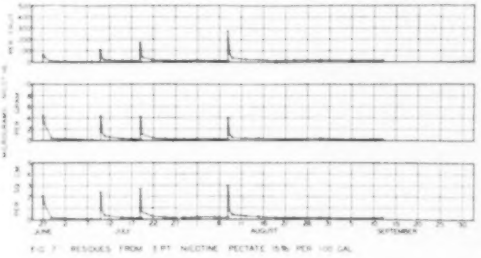


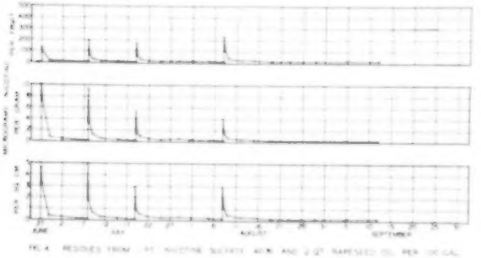


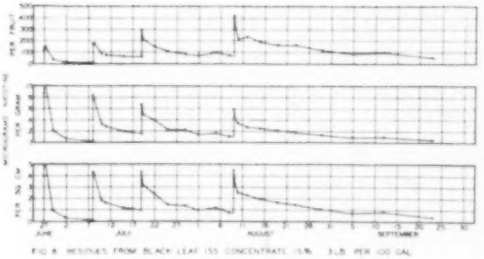












ples from the whole crop would be of much greater value than more concordant results of limited scope.

RESULTS.—The complete residue data for all of the treatments throughout the summer are plotted in figures 1 through 8. The different methods of expressing the residue load show characteristic differences. The amounts of deposit per fruit left by successive sprays in most cases rise steadily as the fruits grow larger. The deposit per unit of weight declines with successive sprays since the weight increases with growth faster than the area available for residue. The deposit per unit of surface area is somewhat variable, but usually remains roughly the same for the successive sprays throughout the season.

Each of the methods of expressing the residue is useful in showing a different property of the material. The per fruit basis eliminates the growth factor and therefore shows that nicotine is actually lost between sprays and is not merely spread thinner by growth of the fruit. The per weight basis allows comparison with other residue data, the majority of which are expressed in this way. The per area basis represents most closely the concentration of residue with which the insect will come in contact on the fruit, and is therefore probably the best measure of effectiveness.

All of the curves, regardless of the particular material, show the same general form. As in the laboratory experiments, by far the most rapid loss of nicotine occurs during drying. The rate changes suddenly at the point of dryness, following which it decreases steadily. It is interesting to note that even the least permanent of the materials still show a measurable nicotine residue after several weeks.

*Fixed vs. Soluble Nicotines.*—The most outstanding differences in the residue curves occur between the fixed nicotines (curves 5, 6, 8) and the soluble forms (curves 1, 2, 3, 4, 7). Although the most rapid loss from the fixed nicotine occurs during drying, a relatively small proportion of the total residue is lost at that time. From the soluble nicotines, on the other hand, from one-half to three-quarters of the whole load is lost during the short period of drying. Previous residue data have indicated that the residue from the soluble nicotines was always far less than that from the fixed forms, since the residue samples for analysis were taken only after drying. The present data show that the initial load is not far different for the two types of material, but that the life of most of the soluble material is extremely short. The differences between the two types of materials are apparently much sharper than previously assumed; in the one, there is little contact action, but a considerable load of nicotine available as a stomach poison over a period of weeks; while in the other, an approximately equal amount of nicotine in a form very active as a contact poison is highly effective over a period not exceeding about five hours, and has dropped to a practically negligible amount in two or three days.

*Mineral vs. Vegetable Oil.*—A comparison of curves 1 and 2 with 4 and 3 respectively shows that there is no appreciable difference between petroleum oil and rapeseed oil in ability to hold either nicotine sulfate or oleate on the fruit. Both the original amounts of nicotine deposited and the rates of loss are practically identical for the two oils with either nicotine compound.

*Variations in Soluble Compounds.*—Two different properties of the compound apparently affect the residues from the soluble compounds. The wetting properties, causing different spraying characteristics and different amounts of run-off, affect the original deposit. The nicotine sulfate (Figs. 1 and 4) having no special wetting ability, shows the highest initial residue throughout. The oleate (Figs. 2, 3) and the pectate (Fig. 7), both having marked wetting ability, show considerably smaller initial deposits. An additional difference between the pectate and the others is the lack of oil and emulsifier. The second factor affecting the residues is the stability of the nicotine compound, which influences the retention of the residue. It can be seen that nicotine sulfate, the salt of the strongest acid and therefore the most stable, is lost considerably more slowly and shows a definitely higher final residue than the other two, between which there is little difference.

*Variations in "Fixed" Nicotines.*—All of the fixed nicotines show the same general characteristics. Each of them shows a loss during drying which is more rapid than at any other period, but which is much less in

extent than that of the soluble nicotines. The subsequent losses are quite slow, the residues even after two or more weeks being greater than those from the soluble nicotines after a very few days. The two quarts of rapeseed oil gave both a higher and a more adherent deposit of nicotine peat than the one pint of blown rapeseed oil. The *Black Leaf 155 Concentrate* gave both an original deposit and a permanence almost identical with that of the nicotine peat and rapeseed oil, the superior sticking qualities of the bentonite apparently being closely balanced by the additional sticking properties given the peat by the oil. *The Black Leaf 155 Concentrate* shows a somewhat greater loss during drying than either nicotine peat treatment, possibly because the material is designed to release a small amount of nicotine as a contact agent.

*Weathering.*—The rainfall between the first and second sprays was much greater than at any other time. It will be seen that all of the fixed nicotines were lost much more rapidly during this period than during any of the others. The nicotine pectate also shows a somewhat greater loss. There is no outstanding difference in the oil-nicotines during the different periods, indicating that the rainfall may tend to affect the fixed nicotines more strongly than it does the oil-nicotines. Assuming no rain immediately after the spray, the effect on the control would be less in any case, since the effectiveness of the fixed forms depends on the maintenance of a deposit for a long period, while the soluble nicotines depend upon a quicker effect for a short period.

SUMMARY.—Detailed residue data were taken throughout the summer on eight experimental nicotine sprays in the field.

The residues were stripped from the apples in the field, eliminating nicotine loss during transportation and making possible the taking of samples immediately after spraying.

On the basis of the results, the following conclusions were reached:

The most rapid loss of nicotine normally occurs during drying of the spray.

The amounts of nicotine originally deposited by soluble nicotine and oil combinations are nearly as high as those by "fixed" nicotines.

The fixed nicotines lose only a small proportion of the original deposit during drying, while the soluble nicotines may lose more than 75 per cent during this period.

Nicotine oleate and nicotine pectate yield a lower deposit at the same concentration than nicotine sulfate, probably because of run-off due to superior wetting properties.

Nicotine oleate and nicotine pectate are lost from the fruit more rapidly and more completely than nicotine sulfate, probably because of lower chemical stability.

Nicotine peat with rapeseed oil and nicotine bentonite without oil give about the same deposit and residue, while the nicotine peat with one pint of blown rapeseed oil gives less, under the experimental conditions.

Mineral oil and rapeseed oil show no apparent differences in either amount or permanence of deposit with nicotine sulfate or with nicotine oleate.

The oil-nicotines are less strongly affected by rain than the fixed nicotines.—3-29-41.

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**SAN FRANCISCO MEETINGS**
**DECEMBER 29, 30, 31, 1941**

# Characteristics of Different Types of Nicotine Sprays

## *II. Codling Moth Control*

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In evaluating representative types of nicotine sprays for field control of codling moth it was intended to design an experiment that would answer the following questions, and at the same time, permit the residue studies described in the previous paper of this series.

1. Would a typical vegetable oil be suitable for use in place of a petroleum oil?
2. What are the relationships in control between a soluble nicotine and oil, a fixed nicotine and oil, and a fixed nicotine without oil?
3. What is the value of an ovicide?
4. What is the value of immediate contact action as compared to the maintenance of a deposit of little contact value?

The orchard was the same rectangular block of 25-year-old Rhode Island Greening trees described in the section on nicotine residues. The fruit was reported to have been 65 per cent insect-injured in 1939. A delayed dormant spray of oil-nicotine sulfate was followed by a pink, calyx and first cover spray of lead arsenate and lime sulfur.

The experimental design was the same triplicated four-tree plot design for the eight treatments as described in the previous paper of this series. It will be seen from table 1 that comparisons between some plots were more important than others, so that one of the restrictions in assignment of treatments to plots was that plot 1 should always be adjacent to plot 2, plot 2 to plot 3, etc. Other restrictions provided that no plot should appear in each block more than once, or should be in either the north, south or central part of the block more than once.

Beginning July 10, counts were made every ten days, when the following data were taken: (1) an estimate of infestation on the tree by counting 300 apples from each four-tree plot, 180 of these being selected at random from parts of the trees readily reached from the ground, 120 in the tops of the trees. These were examined for entrances only and left in place. Thus successive counts might include the same fruit as was previously included in counts, (2), a complete count of all dropped fruits, scored as to wormy or clean fruit, (3), notes on injury to fruit and foliage. At harvest complete counts of all fruits, on the tree or dropped, were made, the picked fruit being scored for worms, stings and for injury from either the eye-spotted bud moth, *Spilonota ocellana* (D. & S.), or the red-banded leaf roller, *Argyrotaenia velutiana* (Walk.). These latter two insects were both present in sufficient numbers to cause some damage, and since their respective injuries were not always distinguishable, the fruit was scored without reference to which insect caused the injury.

The spray schedule has been described in the previous paper of the series.

RESULTS.—The data on picked or tree-sampled fruit in regard to insect injury are presented in table 1. In order to simplify the table, and because several complicating factors as noted below disturbed the estimation of infestation in dropped fruit, they are not included in table 1.

By picking up all dropped fruit it is possible to obtain total infestation figures based on all fruit which set after July 1. These data are presented in table 2 and represent only codling moth entries.

DISCUSSION.—With the method of making pre-harvest estimates of infestation, it is possible to trace the development of the infestation throughout the season. There were three periods of attack: during the first two weeks of July, again during the middle of August, and finally sometime between the 5th and 28th of September. The lull between the first two periods of attack was probably due to early injuries scored as entries showing up as stings when reexamined later. The actual lowering of infestation around the first of September was the result of first brood wormy apples dropping. A large increase in wormy dropped fruit was noted at this time. The three periods of attack may represent three broods of codling moth, or be due to a split first or second brood. It is estimated that more than half of the injuries scored as worms at harvest con-

**Table 1.—Per cent injured fruit.**[1]

| Spray Schedule | Dates of Pre-Harvest Estimates | | | | | | | Harvest (9/28–10/3) | | Bud Moth Leaf Roller |
|---|---|---|---|---|---|---|---|---|---|---|
| | 7/1 | 7/11 | 7/22 | 8/1 | 8/10 | 8/22 | 9/5 | Codling Moth Wormy | Codling Moth Stings | |
| Petroleum oil nicotine sulfate | 0.3 | 0.7 | 0.3 | 0.6 | 1.4 | 1.1 | 0.9 | 5.0 | 13.0 | 5.0 |
| Petroleum oil nicotine oleate | 0.1 | 0.6 | 1.1 | 0.2 | 2.7 | 1.9 | 3.1 | 7.4 | 11.4 | 4.1 |
| Rapeseed oil nicotine oleate | 0.1 | 0.8 | 0.6 | 1.7 | 3.7 | 4.5 | 3.9 | 10.1 | 14.6 | 2.9 |
| Rapeseed oil nicotine sulfate | 0.1 | 1.3 | 1.3 | 0.6 | 1.6 | 1.9 | 1.6 | 5.9 | 9.8 | 1.7 |
| Rapeseed oil nicotine peat | 1.0 | 1.9 | 1.3 | 1.9 | 1.2 | 1.7 | 2.1 | 4.6 | 10.2 | 3.2 |
| Blown rapeseed oil nicotine peat | 1.0 | 3.8 | 1.7 | 1.3 | 2.7 | 5.3 | 3.7 | 8.0 | 18.1 | 4.3 |
| Nicotine pectate | 0.6 | 3.2 | 4.1 | 3.1 | 7.8 | 11.1 | 5.7 | 13.0 | 17.3 | 4.0 |
| *Black Leaf 155 Concentrate* | 0.2 | 1.2 | 2.0 | 1.1 | 2.3 | 3.8 | 2.0 | 4.7 | 9.9 | 3.8 |
| Least significant mean difference (.05) | | | | | | | | 1.6 | 2.1 | 0.8 |
| Least significant mean difference (.01) | | | | | | | | 2.0 | 2.8 | 1.1 |

[1] Unweighted means calculated from 12-tree totals.

tained larvae less than two weeks old.

Differences in insect control in this experiment are not large. The figures are based on a single season's observations. The work is published at the present time primarily as a concomitant to the residue observations. Any conclusions drawn as to the differences in codling moth control of the various schedules, even though they have been shown to be statistically significant, are, therefore, tentative.

With this explanation, the following observations are noted with reference to the aims of the experiment as stated in the introductory paragraph. (1) Rapeseed oil was slightly inferior to petroleum oil for control of codling moth, significantly so when used with nicotine oleate. The ability of the two oils to deposit and hold nicotine was reported in the previous paper in this series to be about equal. They were not found in preliminary laboratory stud-

**Table 2.—Total infestation and drop of fruit set July 1.**[1]

| Schedule | No. Fruit Set July 1 | Wormy Dropped | Clean[2] Dropped | Wormy Picked | Clean Picked | Total Wormy |
|---|---|---|---|---|---|---|
| Petroleum oil nicotine sulfate | 25255 | 1.1% | 7.4% | 5.2% | 86.3% | 6.3% |
| Petroleum oil nicotine oleate | 30345 | 2.3 | 8.3 | 7.3 | 82.1 | 9.5 |
| Rapeseed oil nicotine oleate | 28061 | 1.3 | 10.1 | 8.9 | 79.7 | 11.7 |
| Rapeseed oil nicotine sulfate | 20966 | 4.2 | 7.8 | 5.1 | 82.9 | 7.3 |
| Rapeseed oil nicotine peat | 31181 | 1.5 | 8.5 | 3.9 | 86.1 | 5.8 |
| Blown rapeseed oil nicotine peat | 32532 | 2.9 | 7.7 | 6.2 | 83.2 | 9.1 |
| Nicotine pectate | 28177 | 4.7 | 6.9 | 11.6 | 76.8 | 16.5 |
| *Black Leaf 155 Concentrate* | 26542 | 1.7 | 7.9 | 4.3 | 86.1 | 6.0 |

[1] Means calculated by dividing total fruits from 12 trees by total set July 1.

[2] Too much emphasis should not be put on counts of clean dropped fruit, because the major part of the drop before harvest time was caused by cutting the hay cover crop in the orchard. The trees were pruned low to the ground and it was not unusual that 150 apples per tree were knocked off by this treatment.

ies to differ greatly in their ovicidal effect. (2) Under the conditions of this experiment, no significant differences existed between control in schedules 1, 5 and 8 containing a soluble nicotine and oil, a fixed nicotine and oil and a fixed nicotine without oil. It must be recognized that two different oils and two different fixed nicotines were used in these tests. It is not surprising that the *Black Leaf 155* and the nicotine peat-rapeseed oil schedules gave similar codling moth control, since their deposits of nicotine were quite comparable. It is interesting to note that the petroleum oil-nicotine sulfate schedule was equally good, although leaving a very low residue of nicotine compared to the fixed nicotine schedules. This seems good evidence that the mode of action of soluble nicotine-oil sprays is different from that of fixed nicotine sprays. (3) Schedules 5 and 6 were designed to demonstrate the difference in control with a schedule containing two quarts of rapeseed oil which laboratory tests had shown gave a good egg kill, and a schedule containing one pint of blown rapeseed oil which laboratory tests demonstrated to have negligible ovicidal action. The results of residue analysis showed, however, that differences in nicotine residues between the two schedules were almost proportional to the difference in codling moth control. (4) Nicotine oleate was used in the experiment on the basis of laboratory experiments on *Aphis rumicis* which showed it to have a potent contact action. It appeared less effective than nicotine sulfate, but here again, it was shown to leave a lower residue of nicotine than the sulfate, so that differences in type of action have been obscured by differences in deposit.

Nicotine pectate did not give good control, but *Black Leaf 155 Concentrate* gave surprisingly good control used as it was without oils or other supplements. Here again the control is relative to the deposit of the two materials.

It should be noted that control of codling moth is closely related to nicotine residues when either the fixed or soluble nicotines with oil are considered as a group. The control between the two groups of soluble nicotine with oil and fixed nicotines is not greatly different, but the rates of loss of the deposits differ markedly, again indicating the difference in manner of action of the two groups.

PLANT INJURY.—Some apprehension was felt over the use of petroleum oil in the second cover spray within ten days after the first cover spray which contained lime sulfur. One reason that the schedule was planned that way was to see if differences in injury would appear between the petroleum and rapeseed oil schedules. Sulfur determinations made just before the second cover spray was applied, showed sulfur to be present on the foliage at the rate of 11.7 micrograms per square centimeter, a moderate deposit. No injury occurred that could be attributed to the oil-sulfur complex on any of the trees. There was a little lime-sulfur spotting on the exposed sides of the fruit, but this was present equally on all trees whether they received oil or not. After the third cover spray which was applied on July 8–10 on still hot days noticeable yellowing occurred on trees sprayed with rapeseed oil in areas where trees received the heaviest application of oil. After the first of August a slight roughening of the skin of the fruit around the calyx end appeared on these rapeseed oil sprayed trees. This persisted to harvest where it appeared as a russetting. No other injury of any kind was apparent on any trees.

The oil-nicotine peat residues were unsightly, and persisted until harvest as a dirty black deposit. Where large drops of oil-peat had collected there was often a roughening of the skin under the drop which made removal by wiping difficult.

Although no fungicide was used after the first cover spray, the orchard was almost entirely free from scab at harvest.—3-29-41.

Dr. John Deal, a graduate of Cornell University and of the University of London from which he received his doctor's degree, has been appointed to the Entomology Extension staff of Pennsylvania State College where he will serve under Professor H. E. Hodgkiss.

Dr. Deal takes the place made vacant by the resignation of Dr. E. A. Richmond.

# The Use of Petroleum Oils as Insecticides

## *III. Oil Deposit and the Control of Fruit Tree Leafroller and Other Apple Pests*[1]

P. J. Chapman, G. W. Pearce and A. W. Avens, *New York State Agricultural Experiment Station, Geneva*

In earlier papers of this series (Pearce, *et al.* 1941; Chapman *et al.* 1941) the writers have described a method of determining the quantity of oil deposited on apple bark in spraying and have considered the more important factors affecting deposition. We present in this article data showing the relation of these deposits to insect control. The fruit tree leafroller, *Cacoecia argyrospila* Walker, was the principal insect utilized although some data were obtained on the apple red bug, *Lygidea mendax* Reut. and the rosy apple aphid, *Anuraphis roseus* Baker. These experiments were conducted under field conditions using mature apple trees. Test materials were applied with standard orchard spraying equipment and except as indicated, all spraying was done in the spring while the trees were still dormant.

Techniques.—The results given for fruit tree leafroller control are based on the record of hatch in a series of egg masses that had been located and marked on the trees prior to treatment. Marking was found necessary since after treatment with oil the masses may be very difficult to re-locate, especially after the leaves appear. The marking material used was white adhesive tape. A short strip of tape was wrapped around the twig an inch or two distant from the mass and proximally on the limb in relation to it. Adhesive tape was selected as the marking substance principally because of its persistence to wind, rain and spray. Some markers have remained in place three years after having been affixed. Tape has also seemed to have an advantage over paper tags or cloth strips in that there is no unattached portion to blow about in the wind with the consequent danger of losing the marker or of having it rubbing or striking the egg clusters.

Marking was done in the spring, usually just before or concurrently with the application of treatments. Aside from considerations of the weather this work can best be done in the spring because the egg masses have then become bleached to a light bluish gray and are in distinct contrast to the bark. In the fall and throughout most of the winter the masses are dark brown and are not readily visible. The number of masses marked per tree varied with the intensity of infestation but ranged between 50 and 150. In 1939 approximately 3,000 egg masses were marked in experimental blocks, whereas in 1940 the number exceeded 18,000.

Usually, eggs were not marked higher in the tree than could be reached from a 6-foot stepladder. How well the total number of egg masses of a tree were represented by those marked was determined by the height and growth habits of the trees and by the peculiarities of egg mass distribution for the trees in question. In some orchards, as pointed out by Chapman & Dean (1936), a high percentage of the total masses may be found in the lower half of the tree. However, they may be rather uniformly distributed over the tree in other plantings or even concentrated in the upper half.

The marked egg masses were not removed from the tree until hatching was complete on control trees. Each mass was then examined under a binocular microscope and a record taken of the number of eggs hatched. The masses have been classified under five categories to show how hatching took place. This seems to provide a clearer basis for evaluating the performance of the treatment than can be gained from data based solely on the average number of eggs hatched per cluster. Since these are field experiments some masses show hatch simply because they were missed by the spray. Where incomplete efficiency is shown an examination of the breakdown of the hatch will frequently show whether this is due to the inherent inadequacy of the treatment or is the result of imperfect spray coverage. For example, in series where almost all of the masses show no hatch and only 2 or 3 show complete hatch, it seems logical to

[1] Approved by the Director of the New York State Agricultural Experiment Station for publication as Journal Paper No. 454, June 27, 1941.

conclude that the latter were simply missed by spray. The general color of the mass may also provide useful evidence in such instances. Masses sprayed with oil normally turn brown and contrast sharply in appearance with untreated eggs (Fig. 1).

We have considered the individual egg mass and not the tree as the basic experimental unit in these tests. Under this concept, the tree serves the primary purpose of providing a support for the test units and of randomizing their distribution as targets to the spraying operation. Thus the number of masses involved and not the number of trees would seem to be the most relevant consideration. Single tree plats, some of which were duplicated, have been employed. The experimental area was divided in two parts where a duplicate plat arrangement was used, one tree being located by controlled randomization in each block. Approximately 10 per cent of the trees were reserved as controls, and these were distributed singly through the block.

FIG. 1.—Showing the appearance and amount of hatching taking place in leafroller egg masses treated with lethal and sub-lethal dosages of oil. Untreated masses are shown in the fifth and bottom rows, larval exit holes occurring in the former instance and those produced by *T. torticis* in the latter. In the second and fourth masses of the bottom row both host and parasite emergence occurred. Enlarged.

The results obtained on the apple red bug are based principally on counts of injured terminals. After hatching, the nymphs migrate to the terminal growth to feed, producing a characteristic puncture-pattern in the new leaves. This injury is readily seen and identified. Terminal counts can be started two or three weeks after the blossom period and may be continued almost until frost. These counts provide an estimation of the total insect population of the tree. To compensate for population variations between trees, single tree plats were used and these were replicated four times, on the average.

Spray-drift complications were almost entirely avoided either through the design of the experimental block or through the use of a "spray screen" or through both devices. This screen consisted of a 20 by 20 foot piece of drill cloth which in use was suspended between two 4 by 4 inch wooden spars. The ensemble was mounted on a specially designed four-wheeled carriage thus enabling the spraymen to move the screen from plat to plat.

RESULTS ON LEAFROLLER.—That petroleum oils are toxic to the eggs of the fruit tree leafroller is well known. However, earlier investigations have provided only a general idea of the dosage of oil needed to give control, particularly of the minimum effective dosage. In an effort to obtain precise information on these questions the writers have first considered the effects of the emulsifying agent on the spray mixture in terms of oil deposition and of wetting and spreading. Another vital element in considerations of dosage is the variation in effectiveness exhibited by oils of different composition. In general, this latter subject is outside the scope of the present paper, but it is a factor which the reader should keep in mind when interpreting the data presented. Excepting the commercially prepared oil spray stocks tested, three types of oil were used. These are designated as Oil A, Oil B and Oil C; the specifications on Oil A are given in an earlier paper (Chapman *et al.* 1941).

**Table 1.—Relation of oil concentration to oil deposit, fruit tree leafroller control and tree injury—oil and emulsifier being constant. 1940.**

| Oil Conc. in Spray[1] | Bud Stage When Sprayed | Number Egg Masses Examined | Ave. No. Eggs Hatched per Mass | Per Cent Control | Mg. Oil Deposited per Sq. In. of Bark | Percentage Masses Showing | | | | | Reaction of Tree to Treatment |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | No hatch | 1–10% hatch | 11–35% hatch | 36–99% hatch | Complete hatch | |
| 1% | dormant | 97 | 44.62 | 22.85 | 0.35 | 4.1 | 6.2 | 7.2 | 10.3 | 72.2 | none |
| 2 | dormant | 142 | 14.82 | 74.38 | 0.83 | 45.1 | 16.2 | 9.8 | 11.2 | 17.7 | none |
| 3 | dormant | 223 | 2.12 | 96.33 | 1.16 | 82.9 | 10.3 | 3.2 | 1.3 | 2.3 | none |
| 4 | dormant | 234 | 0.61 | 98.94 | 1.74 | 94.9 | 3.4 | 1.3 | — | 0.4 | sl. retard. |
| 5 | dormant | 229 | 0.60 | 98.96 | 2.20 | 97.0 | 1.3 | 0.4 | 0.9 | 0.4 | sl. retard. |
| 6 | dormant | 253 | 0.04 | 99.93 | 3.29 | 99.2 | 0.8 | — | — | — | slight injury |
| 8 | dormant | 105 | 0.05 | 99.91 | 4.00 | 99.1 | 0.9 | — | — | — | mod. injury |
| 12 | dormant | 136 | 0.00 | 100.00 | 5.24 | 100.0 | — | — | — | — | severe injury |
| 3 | green-tip | 278 | 0.69 | 98.81 | 1.44 | 98.2 | 0.3 | — | 1.2 | 0.3 | none |
| 3 | delayed dormant | 262 | 0.24 | 99.58 | 1.22 | 98.8 | 0.4 | 0.4 | 0.4 | — | none |
| 0 (Control) | | 817 | 57.84[2] | — | | | | | | | |

[1] All lots were "tank-mixed," using Oil A and blood albumin, 2 ounces per 100 gallons, as the emulsifying agent.
[2] Including 2.75% parasitism by *T. tortricis*.

In table 1 we give the results obtained with a series of emulsions which ranged in oil concentration between 1 and 12 per cent. The oil, emulsifier and amount of emulsifier used were constant. From these data the minimum effective oil concentration of the dormant applied sprays would seem to fall somewhere between 3 and 4 per cent. Although there is only 2.61 per cent difference shown in the control efficiency between the two concentrations, it will be seen that 17.1 per cent of the egg masses receiving 3 per cent oil showed some degree of hatching. However, the amount of oil applied in this case—1.16 mg.—must lie close to the minimum effective dosage for oils of the type of Oil A. Essentially complete control was obtained with deposits of 1.44 mg. and 1.22 mg. in the green-tip and delayed-dormant applied sprays. While these sprays might be assumed to be more effective than dormant applications owing to their nearness to the hatching period we have obtained no conclusive evidence to support such an assumption. The minimum effective dosage of Oil A for fruit tree leafroller eggs appears to be approximately 1.3 mg. per square inch bark surface.

In the foregoing, the emulsifier and concentration at which it was used were constant. Furthermore, in the analysis of a twig sample for oil the *total* amount of oil present is determined. It does not provide a measure of how the oil was distributed over the egg mass and bark surface, or, in other words, provide a complete index to the wetting and spreading properties of the emulsion. A question naturally arises as to the effects produced by varying the

**Table 2.—Relation of oil deposit to control of the fruit tree leafroller. Oil[1] concentration and kind and amount of emulsifier being variables. 1940.**

| Oil Conc. in Spray[1] | Kind and Amount of Emulsifier per 100 Gallons | Number of Egg Masses Examined | Ave. No. Eggs Hatched per Mass | Per Cent Control | Mg. Oil Deposited per Sq. In. of Bark | Percentage Masses Showing | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | No hatch | 1–10% hatch | 11–35% hatch | 36–99% hatch | Complete hatch |
| 1% | Blood albumin 2 oz. | 97[2] | 44.62 | 22.85 | 0.35 | 4.1 | 6.2 | 7.2 | 10.3 | 72.2 |
| 2 | Blood albumin 2 oz. | 142[2] | 14.82 | 74.38 | 0.83 | 45.1 | 16.2 | 9.8 | 11.2 | 17.7 |
| 2 | Sodium lauryl sulfate 2 oz. | 78 | 28.42 | 44.56 | 1.04 | 28.2 | 10.2 | 11.5 | 11.5 | 38.6 |
| 4 | *Goulac* (lignin pitch) 12 oz. | 66 | 13.88 | 72.92 | 1.08 | 69.7 | 1.5 | 1.5 | 6.1 | 21.2 |
| 3 | Blood albumin 2 oz. | 223[2] | 2.12 | 96.33 | 1.16 | 82.9 | 10.3 | 3.2 | 1.3 | 2.3 |
| 4 | Sodium lauryl sulfate 4 oz. | 92 | 0.74 | 98.55 | 1.25 | 93.5 | 3.3 | 2.2 | — | 1.0 |
| 4 | Bordeaux mixture 1–2–100 | 70 | 2.60 | 94.92 | 1.36 | 85.7 | 7.1 | 2.8 | — | 4.4 |
| 2 | Triethanolamine oleate 56 cc. | 106 | 1.02 | 98.01 | 1.38 | 94.3 | 1.9 | 1.9 | — | 1.9 |
| 4 | Blood albumin 4 oz. | 86 | 0.32 | 99.37 | 1.50 | 98.8 | — | — | 1.2 | — |
| 4 | Blood albumin 2 oz. | 234[2] | 0.61 | 98.94 | 1.74 | 94.9 | 3.4 | 1.3 | — | 0.4 |
| 4 | (No emulsifier) | 49 | 0.02 | 99.96 | 1.76 | 97.9 | 2.1 | — | — | — |
| 4 | Soap flakes 8 oz. | 85 | 0.35 | 99.31 | 1.89 | 96.5 | 2.3 | — | 1.2 | — |
| 4 | Diglycol laurate 3 oz. | 70 | 0.00 | 100.00 | 2.08 | 100.0 | — | — | — | — |
| 4 | Gum arabic 8 oz. | 42 | 0.26 | 99.49 | 2.10 | 92.9 | 7.1 | — | — | — |
| 2 | Skimmilk powder 8 oz. | 53 | 0.53 | 98.96 | 2.79 | 96.4 | 1.8 | — | 1.8 | — |
| 4 | Bancroft clay 1 lb. | 65 | 0.00 | 100.00 | 2.82 | 100.0 | — | — | — | — |
| Control—Wealthy | | 211 | 51.27[3] | | | | | | | |
| Control—Maiden Blush | | 817 | 57.84[3] | | | | | | | |

[1] All lots were "tank-mixed" using Oil A throughout.
[2] Maiden Blush series.
[3] Includes 2.22% parasitism by *T. tortricis* in Wealthy series and 2.75% in Maiden Blush series.

emulsifying agent, of using materials which differ radically in their wetting and spreading action. Data having a bearing on this question are given in table 2.

The entries in table 2 have been arranged in the order of their oil deposition. Attention is called to the relation shown between these total deposits and control. These data would appear to corroborate the conclusion drawn from table 1 data, namely, that 1.3 mg. oil is the approximate minimum effective dosage. There is the further indication that kill of leafroller eggs is related rather directly to the quantity of oil deposited regardless of how it becomes deposited. In saying this we do not wish to imply that the wetting and spreading function of the emulsifier, *per se*, is unimportant. We interpret the irregularity shown in the deposit-control relationship where control was incomplete (the first five entries) to differences in the wetting and spreading of the mixture. However, there is little evidence of such an effect among those lots which fall at or near the assumed minimum effective dosage (entries 5 to 8 inclusive). And these include such different substances, judged by their wetting and spreading properties, as blood albumin, sodium lauryl sulfate, bordeaux mixture, and triethanolamine oleate.

From a practical viewpoint it appears that the dominant consideration involved in rating the effectiveness of an oil spray for leafroller control is the quantity of oil it will deposit on the tree, assuming of course, that the same oil is used in sprays compared. In actual use insecticides are ordinarily not employed at the minimum effective dosage, but at the minimum plus a margin to cover the variables incident to use. Under such conditions lesser forces become submerged by the dominant force or forces operating.

In the foregoing we have been concerned with home-mixed or tank-mixed emulsions. The performance of sprays prepared from 14 commercially prepared concentrated oil emulsions and emulsible oils[1] is given in table 3.

While there is a general trend shown here between deposit and control, it is not a high correlation. Neither would these data substantiate the conclusion that 1.3 milligrams was the minimum effective dosage for leafroller. The differences shown are attributed to variations (1) in the kind and amount of emulsifier used, (2) the method of processing or mixing the stock product, and (3) the type of oil utilized. Differences in the deposit can be explained by variables one and two. (See Chapman *et al.* 1941.) An explanation of

**Table 3.—Results obtained with commercially prepared oil emulsions and emulsible oils in fruit tree leafroller and apple red bug control. 1940. All lots tested at a four per cent actual oil concentration.**

| | | Leaf Roller | | | | Percentage Leaf Roller Masses Showing | | | | | Percentage Control Efficiency Against Red Bug[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lot No.[1] | Percentage Oil in Stock Product | Number masses examined | Ave. no. eggs hatched per mass | Per cent control | Mg. Oil Deposited per Sq. In. of Bark | No hatch | 1–10% hatch | 11–35% hatch | 36–99% hatch | Complete hatch | |
| 1 (a) | 66 | 87 | 45.56 | 20.8 | 1.23 | 2.3 | 5.8 | 11.3 | 7.0 | 73.6 | 50.3 |
| 2 (b) | 83 | 75 | 37.31 | 35.2 | 1.28 | 18.7 | 10.6 | 6.7 | 13.3 | 50.7 | 73.7 |
| 3 (b) | 83 | 68 | 29.38 | 48.9 | 1.31 | 16.2 | 16.2 | 14.7 | 19.1 | 33.8 | 83.1 |
| 4 | 90 | 93 | 22.27 | 61.3 | 1.69 | 24.7 | 19.4 | 11.8 | 24.7 | 19.4 | — |
| 5 | 83 | 87 | 24.73 | 57.0 | 1.71 | 25.3 | 23.0 | 12.6 | 9.2 | 29.9 | 73.7 |
| 6 (a) | 83 | 73 | 32.19 | 44.1 | 1.82 | 11.0 | 9.6 | 19.2 | 24.6 | 35.6 | 72.1 |
| 7 (c) | 83 | 86 | 0.0 | 100.0 | 1.85 | 100.0 | — | — | — | — | 93.3 |
| 8 | 99 | 93 | 2.59 | 95.5 | 1.92 | 94.6 | — | 1.1 | 1.1 | 3.2 | 93.3 |
| 9 (c) | 95 | 83 | 0.00 | 100.0 | 1.97 | 100.0 | — | — | — | — | 99.8 |
| 10 (d) | 98.5 | 72 | 7.44 | 87.1 | 2.04 | 62.5 | 12.5 | 9.7 | 9.7 | 5.6 | — |
| 11 | 99 | 101 | 1.62 | 97.2 | 2.13 | 84.1 | 8.9 | 4.0 | 2.0 | 1.0 | 98.3 |
| 12 (e) | 98.5 | 86 | 7.87 | 86.3 | 2.51 | 76.7 | 3.5 | 7.0 | 2.3 | 10.5 | 93.3 |
| 13 (e) | 83 | 84 | 0.00 | 100.0 | 3.38 | 100.0 | — | — | — | — | 93.3 |
| 14 (d) | 83 | 90 | 0.35 | 99.4 | 3.38 | 96.7 | 2.2 | — | 1.1 | — | 96.5 |
| Control | — | 228 | 57.55 | — | — | — | — | — | — | 100.0 | |

[1] The lots so paired (a) (a), (b) (b), etc. were supplied by the same manufacturer. In each instance the same oil is reported to have been used, the two products differing from each other in the emulsifier employed. Represented in this series are products offered by the following manufacturers: Sherwin-Williams Company, California Spray-Chemical Company, Shell Oil Company, James Good and Company, Standard Oil Company of New Jersey, General Chemical Company, B. G. Pratt, Standard Oil Company of Indiana and Standard Agricultural Chemical Company. There is no relation between the order of listing just given and the numbers in the table.

[2] Based on counts of injured terminals.

[1] As the term suggests, "concentrated oil emulsions" are oil spray stocks which are emulsions in a concentrated form: they have the consistency of a thin white or grayish paste and normally contain not more than 85 per cent oil. "Emulsible oils" have the general appearance of oils and consist essentially of an oil in which an emulsifying agent is dissolved.

the dissimilarity shown between data of tables 1 and 2 and that appearing in table 3 on the deposit-control relationship lies chiefly in the fact that in the former instances the same oil was used throughout whereas in table 3 several classes of oil are involved. In other words, while 1.3 mg. oil may represent the minimum effective dosage of Oil A, greater or lesser dosages may be needed for other types of oil. Some indications in this direction are shown in the data on the paired lots of table 3. We shall discuss the behavior of oils of various compositions in future reports.

Since petroleum oils as commonly employed are not effective against all of the oil. Unfortunately, it was necessary to use data involving two types of oil which differ in their toxicity to leafroller eggs. While this complicates the evidence, we believe the essential facts are clear.

The difference shown between 1 per cent *Elgetol* and 0.5 per cent *Elgetol* when combined with 3 per cent oil is explained on the basis of oil deposit. *Elgetol*, in addition to the toxicant, contains a considerable quantity of wetting agents. Thus in using one gallon of *Elgetol* with the oil we incorporate twice the quantity of wetting agents in the mixture as with a half-gallon. And since some wetting agent is already present, in the form of the emulsifier,

**Table 4.—Results obtained with dinitro compounds used alone and combined with oil in fruit tree leafroller control. 1938 and 1940.**

| Amount of Oil, Emulsifier, and Toxicant per 100 Gallons | No. Egg Masses Examined | Average No. Eggs Hatched per Mass | Per Cent Control | Mg. Oil Deposited per Sq. In. of Bark | Percentage Masses Showing | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | No hatch | 1–10% hatch | 11–35% hatch | 36–99% hatch | Complete hatch |
| **McIntosh Series** | | | | | | | | | |
| 4% Oil A, *Goulac* 1 lb. | 36 | 5.22 | 91.7 | — | 86.5 | 2.7 | 2.7 | — | 8.1 |
| 4 Oil B, *Goulac* 1 lb. | 36 | 19.94 | 68.2 | — | 36.1 | 13.9 | 11.2 | 19.4 | 19.4 |
| 3 Oil B, *Goulac* 1 lb., 14.4 DNOCHP[1] | 39 | 23.38 | 62.7 | — | 46.2 | 5.1 | 15.4 | 10.2 | 23.1 |
| **Maiden Blush Series** | | | | | | | | | |
| 3% Oil B, *Goulac* 12 oz., 14.4 oz. DNOCHP | 278 | 21.70 | 62.5 | 0.82 | 29.1 | 19.4 | 10.1 | 17.6 | 23.8 |
| 3 Oil B, bordeaux 1–2–100, 14.4 oz. DNOCHP | 134 | 10.34 | 82.1 | 1.31 | 51.5 | 20.1 | 9.9 | 7.4 | 11.1 |
| 3 Oil B, bl. alb. 2 oz. 14.4 oz. DNOCHP | 252 | 3.43 | 94.1 | 1.56 | 86.1 | 5.5 | 2.8 | 2.1 | 3.5 |
| 3 Oil B, bl. alb. 2 oz. plus oxalic acid, 14.4 DNOCHP | 135 | 1.01 | 98.2 | 1.82 | 80.8 | 14.8 | 3.7 | — | 0.7 |
| 3 Oil A, blood albumin 2 oz. | 733 | 1.02 | 98.2 | 1.28 | 93.3 | 3.7 | 1.2 | 1.0 | 0.8 |
| 3 Oil A, bl. alb. 2 oz. 12.0 DNOCHP | 291 | 1.00 | 98.2 | 1.32 | 95.5 | 2.1 | 0.7 | 1.0 | 0.7 |
| 1 *Elgetol* | 247 | 55.06 | 4.8 | — | 0.0 | 2.0 | 2.0 | 1.6 | 94.4 |
| 3 Oil A, bl. alb. 1 oz., 1.0% *Elgetol* | 133 | 9.95 | 82.8 | 0.82 | 65.4 | 7.5 | 7.5 | 6.1 | 13.5 |
| 3 Oil A, bl. alb. 1 oz., 0.5% *Elgetol* | 281 | 1.19 | 97.9 | 1.58 | 94.6 | 1.5 | 1.5 | 1.5 | 0.9 |
| Control (McIntosh Series) | 62 | 62.71[2] | — | — | — | — | — | — | 100.0 |
| Control (Maiden Blush Series) | 817 | 57.84[2] | — | — | — | — | — | — | 100.0 |

[1] DNOCHP = dinitro-*o*-cyclo-hexyl-phenol. *Elgetol* contains 22% sodium dinitro-*o*-cresylate.
[2] Including 3.65% parasitism by *T. tortricis* in McIntosh series and 2.75% in Maiden Blush series.

pests for which dormant and semidormant sprays are used, there has been interest in combining oil and various toxicants in the hope that a universally effective treatment might be found. Dinitro derivatives of certain phenolic compounds have shown promise in this connection. It has seemed relevant to a general investigation of oils as insecticides to determine what effects, if any, were produced by the addition of these dinitro insecticides. The results of such tests involving the leafroller are shown in table 4. These data and others not given indicate that dinitro-*o*-cyclohexyl-phenol, sodium dinitro-*o*-cresylate and dinitro-*o*-cresol at the concentrations and in the manner used show little or no evidence of toxicity to leafroller eggs, either when used alone or combined with run-off may be caused where as much additional wetting agents are added as occurs in a gallon of *Elgetol* with a consequent decrease in oil deposit.

Eggs of the fruit tree leafroller are sometimes heavily parasitized by *Trichogrammatomyia tortricis* Girault. An opportunity was afforded in one orchard to determine the effects of dormant spray treatments on this parasite since 89.4 per cent of the leafroller eggs in the block were so infested. It is planned to publish elsewhere a report on the biology of this little known species. The life cycle of *T. tortricis* seems to be specifically integrated with that of the fruit tree leafroller. Emergence of parasite adults occurs some five or six weeks after the period when the caterpillars hatch from unparasitized eggs. It

takes place at a time when newly laid eggs of the next generation of the host are available for oviposition. Egg masses showing exit holes made by leafroller caterpillar and *T. tortricis* adults are compared in figure 2.

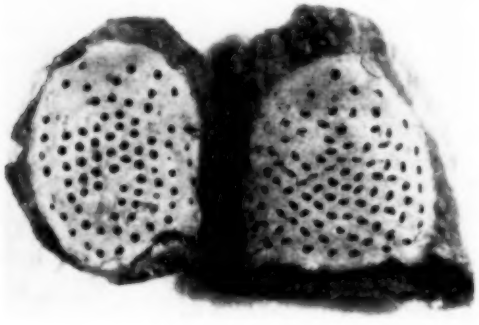

FIG. 2.—Leafroller egg masses showing exit holes produced by adults of the parasite *T. tortricis* (left) and by leafroller larvae (right). Enlarged.

The effects of various dormant treatments on *T. tortricis* are given in table 5. In general, parasitized eggs appear to react in almost an identical manner to the oil and other toxicants as unparasitized eggs. Although there is an indication that some parasites might survive the minimum effective dosage of oil given for the leafroller (1.3 mg. per sq. in. of bark for Oil A), for all practical purposes the treatments that destroy leafroller eggs destroy *T. tortricis* as well.

RESULTS ON RED BUG.—The eggs of the apple red bug occur singly or in pairs and are deeply inserted in apple twigs and watersprouts. Only the tip end of the egg remains visible at the bark surface. Because of the obvious differences in location and nature of protection between leafroller and red bug eggs, one might expect to find differences in their response to insecticides. The results obtained with various oil and oil-dinitro sprays are given in tables 3 and 6.

The minimum quantity of oil required to give control of red bug appears to be slightly greater than for the leafroller. If an efficiency of 95 per cent represents the approximate lower limit of "control" for field tests, then perhaps 1.5 mg. oil per square inch of bark is the indicated effective minimum for oils of the type of Oil A. The results obtained in table 6 where sodium lauryl sulfate and triethanolamine oleate emulsions are compared indicates a difference in wetting and spreading capacities. Sodium lauryl sulfate is the better wetting agent at the concentrations used. This conceivably might cause sufficiently better penetration of oviposition wounds and wetting of the eggs to give better control.

As with the leafroller, the various oils represented in the tests did not show the same degree of toxicity to red bug eggs (Table 3). Evidence on this point is not as clear-cut as with leafroller, but there seems to be no mistaking this general fact.

**Table 5.—Results obtained with oil and oil plus dinitro compounds in the treatment of fruit tree leafroller egg masses heavily parasitized with *Trichogrammatomyia tortricis* Girault. 1939.**

| AMOUNT OF OIL, EMULSIFIER AND TOXICANT[1] PER 100 GALLONS | NUMBER EGG MASSES EXAMINED | AVERAGE NUMBER *T. tortricis* ADULTS OR LEAFROLLER LARVAE EMERGED | PERCENTAGE CONTROL EFFICIENCY | MG. OIL DEPOSITED PER SQ. IN. OF BARK |
|---|---|---|---|---|
| 3% oil, *Goulac* 1 lb. | 19 | 11.94 | 71.4 | 0.69 |
| 4 oil, *Goulac* 1 lb. | 43 | 6.35 | 84.8 | 1.10 |
| 3 oil, *Goulac* 1 lb. plus 14 oz. DNOCHP | 32 | 4.75 | 88.6 | 1.09 |
| 4 oil, *Emulphor EL.* 40 cc. | 40 | 4.92 | 88.2 | 1.22 |
| 5 oil, *Emulphor EL.* | 44 | 0.00 | 100.0 | 1.45 |
| 4 oil, *Goulac* 1 lb. (oversprayed) | 43 | 0.58 | 98.6 | 1.47 |
| 3 oil, *Goulac* 1 lb. plus 1 gal. *Elgetol* | 37 | 1.13 | 97.3 | 1.51 |
| 4 oil, *Emulphor EL.* 40 cc. (oversprayed) | 31 | 0.00 | 100.0 | 1.60 |
| 5 oil, bordeaux mixture 1–2–100 | 41 | 0.00 | 100.0 | 1.88 |
| 5 oil, blood albumin 2 oz. | 36 | 0.25 | 99.4 | 2.76 |
| Control | 87 | 41.77[2] | — | — |

[1] *Elgetol* contains 22 per cent sodium dinitro-*o*-cresylate. DNOCHP refers to dinitro-*o*-cyclo-hexyl-phenol.
[2] 89.4 per cent of the eggs parasitized with *T. tortricis*.

The dinitro insecticides have proved ineffective against red bug and when combined with oil seem, if anything, to exert a slight inhibiting action on the oil. The effects on oil deposit and control caused by combining one-half and 1 gallon of *Elgetol* with an oil emulsion have already been discussed in connection with the leafroller. Similar data appear in table 6.

standpoint of the rosy aphid, the plat technique employed here left much to be desired. But aphid infestation data were taken anyway for what it might be worth in suggesting general trends. Some of these data are given in table 7. Oils as ordinarily used are poor aphicides. This was strikingly demonstrated in that part of the orchard where the grower applied a 5

**Table 6.—Results obtained with oil and oil plus dinitro compounds in apple red bug control. 1940.**

| AMOUNT OF OIL, EMULSIFIER, AND TOXICANT[1] PER 100 GALLONS | NO. TREES | RESULT BASED ON INJURED | AVERAGE NO. PER TREE | AVERAGE DEVIATION FROM MEAN | PERCENTAGE CONTROL EFFICIENCY | MG. OIL DEPOSITED PER SQ. IN. OF BARK |
|---|---|---|---|---|---|---|
| | | R. I. Greening Series | | | | |
| 4% Oil A, blood albumin 2 oz. | 2 | terminals | 11.0 | 5.0 | 97.9 | 2.03 |
| 4 " Oil C, blood albumin 2 oz. | 1 | terminal | 7.0 | — | 98.7 | 1.71 |
| Control | 3 | terminals | 541.0 | 81.3 | — | — |
| | | McIntosh Series | | | | |
| 5 Oil A, blood albumin 2 oz. | 6 | terminals | 54.3 | 11.7 | 97.8 | 1.80 |
| 5 Oil C, blood albumin 2 oz. | 3 | terminals | 44.3 | 6.2 | 98.2 | 1.80 |
| 5 Oil A, sodium lauryl sulfate (IN-181) 2 oz. | 3 | terminals | 94.3 | 54.4 | 96.2 | 1.41 |
| 5 Oil A, triethanolamine oleate 56 cc. | 4 | terminals | 217.9 | 28.2 | 91.3 | 1.94 |
| 3 Oil A, bl. alb. 1 oz. plus *Elgetol* 1 gal. | 3 | terminals | 1014.6 | 212.2 | 59.4 | 0.98 |
| 4 Oil A, bl. alb. 1 oz. plus *Elgetol* ½ gal. | 3 | terminals | 336.3 | 67.1 | 86.5 | 1.25 |
| 4 Oil A, bl. alb. 2 oz. plus 12 oz. DNOCHP | 3 | terminals | 218.3 | 60.4 | 91.3 | 1.29 |
| 5 Oil A, bl. alb. 2 oz. plus 6 oz. DNOCHP | 2 | terminals | 92.0 | 13.0 | 96.3 | 2.21 |
| Control | 5 | terminals | 2500.0 | — | — | — |
| Nicotine sulfate 1-800 (calyx application) | 2 | fruit | 1.9[2] | 0.67 | 94.6 | — |
| 5% Oil A, blood albumin 2 oz. | 2 | fruit | 2.4[2] | 0.81 | 93.5 | 1.81 |
| Control | 5 | fruit | 36.4[2] | 5.53 | — | — |

[1] *Elgetol* contains 22 per cent sodium dinitro-*o*-cresylate while DNOCHP refers to dinitro-*o*-cyclo-hexyl-phenol.
[2] Percentage fruit injured per tree.

There is a fundamental difference in the records on the fruit tree leafroller and red bug that should be kept in mind when interpreting the results given. With the leafroller, data are presented on the effect of the treatment on marked egg masses. Consequently such data constitute a direct measure of the efficiency of the treatment and are unaffected by variations in infestation between trees. The red bug data, however, consist of estimates of tree populations of the insect arrived at indirectly by counts of injured terminal growth or fruit. While records taken in this way are sufficiently accurate for most purposes, they cannot be considered more than approximations. They are also affected by the normal variation in the population between trees. The leafroller data would thus appear to lend itself to much more precise interpretation than would be true of that given on the red bug.

RESULTS ON THE ROSY APHID.—The rosy apple aphid was present in outbreak proportions in western New York orchards in 1939, including the planting being used for our principal leafroller tests. From the

per cent *Goulac* emulsion of Oil A and where comparable treatments were used in the experimental area. These formulae proved entirely effective against fruit tree leafroller but outwardly they appeared to have little effect on the rosy aphid. Except for about 10 per cent of the trees in the experimental area approximately 50 per cent of the crop in this entire orchard was damaged by the aphid.

For a measurement of the separate effects of oil on rosy apple aphid eggs the best controls available were the trees that had been treated with dinitro compounds and oil. These showed an average fruit injury at harvest of 2.53 per cent. The first entry in table 7 represents the effect on the aphid of a dosage of oil that will kill leafroller eggs. The degree of aphid control seems to have been low. This fact may not be clearly evident from the aphid colony data, but since 45.73 per cent of the fruit from these trees was aphid-injured, the degree of protection supplied by the oil could not have been large.

That oils of the type used will ultimately give control of the aphid is indi-

cated by the results obtained in overspraying with 4 per cent oil. In this instance the trees received what was considered twice the usual gallonage of spray needed to completely cover them. The reduction in aphid injury noted over trees receiving the usual dosage probably should not be attributed solely to increased oil deposit; the oversprayed trees no doubt received a much more uniform cover of oil in the amount indicated than could be accomplished with a lesser gallonage. An explanation of the difference in 4 mg. of oil per square inch of bark where an oil of the type of Oil A is involved.

SUMMARY.—A correlation was found to exist between the quantity of oil deposited on apple bark in spraying as determined by the analysis of a sample of twigs and the efficiency of the treatment in killing the eggs of the fruit tree leafroller. Expressed in terms of a surface unit, the minimum effective dosage required for this species is approximately 1.3 mg. oil per square inch of bark. This is the dosage when using the type of oil utilized in most

**Table 7.—Results obtained with oil and oil-dinitro compounds in rosy apple aphid control. 1939.**

| Amount of Oil and Toxicant per 100 Gallons[1] | Number Trees Examined | Average Number Aphid Colonies per Tree | Average Deviation from Mean | Mg. Oil Deposited per Square Inch of Bark |
|---|---|---|---|---|
| 4% oil | 4 | 587.5 | 104.7 | 1.57 |
| 4 oil oversprayed | 4 | 159.5 | 71.0 | 2.24 |
| 5 oil ground sprayed | 4 | 268.5 | 45.2 | 2.22 |
| 5 oil tower sprayed | 4 | 371.2 | 21.3 | 2.39 |
| 2 *Elgetol* | 1 | 1.0 | — | — |
| 3 oil plus 1% *Elgetol* | 1 | 52.0 | — | 1.51 |
| 3 oil plus 14 oz. DNOCHP | 2 | 44.5 | 17.5 | 1.08 |
| 3 oil plus 14 oz. DNOC | 2 | 23.5 | 20.2 | 0.97 |

[1] *Elgetol* contains 22% sodium dinitro-o-cresylate. DNOCHP refers to dinitro-o-cyclo-hexyl-phenol, and DNOC to dinitro-o-cresol.

control indicated between trees sprayed from the ground and from the tower probably lies in the manner of rosy aphid egg distribution on the tree. Aphid injury and presumably the location of eggs as well, is largely restricted, usually, to the lower and inner portion of the tree. A sprayman on the ground should be in a better position to cover this zone of the tree completely than could an operator on top of the spraying machine.

It cannot be said that the quantity of oil needed to control the rosy aphid was much more than indicated from the data obtained in 1939. Certainly, the petroleum oils in use today show a lower degree of toxicity to rosy aphid eggs than to those of the leafroller, red bug, European red mite and others. And in using a material showing this degree of utility, the standard of "control" might be expected to cover considerable latitude, especially since an aphid is involved. For one thing, the effective dosage for the aphid probably exceeds or at least approximates the maximum dosage that a tree ordinarily would tolerate. The minimum effective dosage of oil needed to "control" this species in 1939 appeared to lie between 3 and of the tests reported. Greater or lesser amounts will be required for other petroleum oil types available. While oil deposition may be profoundly affected by the kind and amount of emulsifying agent used in the spray mixture, control was found rather directly related to the quantity of oil finally deposited regardless of how it became deposited. Thus there was little evidence obtained of any important effect on efficiency imparted by the emulsifier acting strictly in its role as a wetting and spreading agent. The dinitro insecticides used proved ineffective against the eggs of the leafroller. These materials also failed to increase the efficiency of the treatment when combined with oil over that obtained separately with the oil.

The fruit tree leafroller egg parasite, *Trichogrammatomyia tortricis* Girault, was found to show essentially the same reaction to the various treatments tested as unparasitized eggs.

Oil spray formulae advised for fruit tree leafroller control should in most cases, prove effective against the apple red bug. However, the data obtained suggest that approximately 1.5 mg. oil is the minimum

effective deposit for this pest. The function of the emulsifier in wetting and spreading appears to constitute a more important factor in the control of the red bug than of leafroller. The dinitro compounds gave negative results on red bug either when used alone or combined with oil.

Dosages of oil found effective against the leafroller and red bug proved ineffective against the rosy apple aphid in 1939 when the pest occurred in outbreak numbers in the experimental orchard. Control can eventually be effected with oil sprays containing a high percentage of oil but it is doubtful that they would be acceptable treatments owing to the danger of tree injury at effective deposits. Between 3 and 4 mg. was the indicated minimum effective deposit per square inch of bark under infestation conditions obtaining in 1939.—7-3-41.

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# Compatibility of Bordeaux Mixture and Cube

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Bordeaux mixture, as commonly prepared, is neutral or slightly alkaline and the effect of this mixture on the constituents of cube appeared worthy of careful study.

It is known that rotenone-bearing insecticides become less toxic when used in the presence of alkalies, owing to oxidation of rotenone and deguelin (LaForge & Haller 1934). Freshly prepared bordeaux-cubé sprays have been used by Walker (1937) against the European corn borer, *Pyrausta nubilalis* (Hbn.), and by Huckett (1938) against the Mexican bean beetle, *Epilachna varivestis* Muls. This paper reports tests made under laboratory and field conditions of bordeaux-ground cube root combinations at various intervals after preparation.

LABORATORY TESTS.—Bordeaux mixture (4–6–50) was prepared in the regular manner, and to this mixture cube containing 5.7 per cent of rotenone and 24.5 per cent of total extractives was added to make a spray of 0.015 per cent rotenone content. This suspension was stored in glass bottles in the laboratory, and samples were removed at monthly intervals to determine by colorimetric (Goodhue 1936) and goldfish (Gersdorff 1935) analyses the deterioration that had taken place.

METHODS OF ANALYSIS AND TOXICITY DETERMINATION.—The bordeaux mixture-cube was shaken for several minutes and a 100-ml. sample was removed by means of a pipette. This sample was then divided into units of 10 ml. each. The 10-ml. samples were immediately evaporated to dryness in a carbon dioxide flask on a steam bath with the assistance of a vacuum air stream. The residue was extracted and filtered six times by thoroughly washing with warm, dry chloroform. By this method only a trace of copper could be detected in the extract with the potassium ferrocyanide test. The chloroform was then evaporated to dryness and the residue was dissolved in 10 ml. of acetone. Aliquots of 2 ml. each were used for the colorimetric analysis. For the goldfish analysis the residue was dissolved in 20 ml. of acetone, and 1 ml. of this solution was added to 1 liter of water.

The previously mentioned procedure was compared with the colorimetric method by the use of an equivalent sample of cube to determine the discrepancy, if any, in the modified technique. A weighed sample of cubé was dis-

solved in acetone and made up to a volume to contain the same amount of rotenone per milliliter as the cube-bordeaux mixture. When sampled immediately after mixing, no difference could be detected between the cubé dissolved in acetone and the cube mixed with bordeaux and rapidly evaporated to dryness.

To determine the toxicity to larvae of the Mexican bean beetle under laboratory conditions, the bordeaux mixture-cube was applied to bean leaves by means of a small standardized atomizer developed by H. A. Waters, of Ohio State University. It was found by analysis that four reservoirs full would deposit 16 micrograms of rotenone per square centimeter. After the spray had dried, Mexican bean beetle larvae were confined on the treated leaves by means of a small glass cylinder, and mortality was determined after 96 hours. Leaves were changed every 48 hours.

**Table 1.—Deterioration of cubé when combined with bordeaux mixture as determined by various criteria.**

| Time After Mixing, Days | Rotenone Content by Colorimetric Test, Mg.[1] | Goldfish Survival Time, Min. | Mortality of Mexican Bean Beetle Larvae, Per Cent[2] |
|---|---|---|---|
| 1/24 | 0.6 | 165 | 70 |
| 30 | .45–.50 | 195 | 60 |
| 62 | .35–.38 | 220 | 60 |
| 92 | .30–.32 | 237 | 50 |
| 124 | .31–.32 | 229 | 55 |
| 152 | .30–.31 | 241 | — |
| 183 | .29–.32 | 232 | — |
| 216 | .30–.35 | 235 | 50 |
| 244 | .28–.33 | 240 | — |
| 276 | .30–.33 | 236 | 55 |
| 317 | .30–.35 | 232 | 45 |
| 339 | .30–.32 | 242 | — |
| 370 | .32–.32 | 237 | — |
| 469 | .28–.32 | 235 | — |

[1] Based on a 2-cc. aliquot.
[2] Based on original deposit of 16 micrograms per square centimeter 1 hour after mixing.

LABORATORY RESULTS.—Analyses by the colorimetric method, when a cube sample was used as a control, showed no decrease in rotenone in the bordeaux solution after it had been mixed for 1 hour. Later analyses indicated about a 20-per cent reduction after 30 days, followed by a further 20-per cent reduction in 62 days. After 3 months the rotenone had decomposed 50 per cent, but in the remaining 12 months no further change was detected (Table 1). The goldfish survival time and the mortality data for the Mexican bean beetle larvae (Table 1) corroborate the colorimetric results.

FIELD TESTS.—In addition to the laboratory studies, a bordeaux mixture-cube combination containing 0.02 per cent of rotenone was prepared on March 31, 1939, and 10 weeks later, on June 7, was used in field tests against the Mexican bean beetle. The cubé used was from the same lot as that employed in the laboratory tests. At the time application was made in the field, analysis indicated that the cubé had deteriorated approximately 50 per cent.

In two experiments on snap beans the mixture was compared with a number of spray combinations, including the recommended 0.015-per cent rotenone spray and an 0.01-per cent rotenone spray (both made with cube) as well as an untreated check. Each material and the check was replicated four times in each experiment. Applications were made with continuous-pressure knapsack sprayers at the rate of 100 to 110 gallons per acre.

FIELD-TEST RESULTS.—The results are summarized in table 2. The data were statistically analyzed, and tests of significance were made by the method of the analysis of variance (Snedecor 1937).

As the tabulated data show, there was no difference in the control obtained with the three sprays 2 weeks after application, and all are significantly better than the untreated check. Under practical conditions a second application would have been made 10 days or 2 weeks after the first. This was omitted to obtain information on residual effect. The estimates of injury 3 and 4 weeks after spraying show no significant differences between the three sprays, and all remained significantly better than the check. The greater injury in the 0.01-per cent rotenone plots after 4 weeks may indicate a tendency for the 0.01-per cent rotenone spray to have less residual effect than the other two, but in these tests the differences are not significant.

These data indicate that a bordeaux mixture-cube combination made up to contain 0.02 per cent of rotenone, but which had deteriorated about one-half in rotenone at the time of use, was equal to

a freshly prepared 0.015 per cent rotenone spray in effectiveness against the Mexican bean beetle. This may be due in part to the excellent sticking properties of bordeaux mixture and also to the fact that, as observed by Huckett (1938), bordeaux mixture in itself possesses considerable merit in reducing the feeding of the Mexican bean beetle.

Table 2.—Comparative effectiveness against the Mexican bean beetle of bordeaux mixture-cubé spray prepared 10 weeks prior to application and freshly made cubé sprays in field tests at South Point, Ohio, 1939.

| Spray Combination | Rotenone Content at Time of Application, Per Cent | Experiment 1 Mean Estimated Per Cent Beetle Injury After Spraying | | | Experiment 2 Mean Estimated Per Cent Beetle Injury After Spraying | | |
|---|---|---|---|---|---|---|---|
| | | 2 Weeks | 3 Weeks | 4 Weeks | 2 Weeks | 3 Weeks | 4 Weeks |
| Bordeaux mixture 4-6-50 plus cube | 0.01 | 5.0 | 15.0 | 23.8 | 5.0 | 20.0 | 28.8 |
| Cube | .015 | 5.0 | 13.8 | 26.2 | 5.0 | 20.0 | 28.8 |
| Cube | .01 | 5.0 | 16.2 | 35.0 | 5.0 | 22.5 | 40.0 |
| Check (untreated) | — | 33.8 | 56.2 | 66.2 | 33.8 | 55.0 | 68.8 |
| Required difference for odds of 99 to 1 | | 14.9 | 12.6 | 22.5 | 8.1 | 9.3 | 14.0 |

SUMMARY.—The combining of ground cube root with bordeaux mixture has been studied in the laboratory and under field conditions.

In the laboratory colorimetric and goldfish analyses indicated about a 20-per cent reduction in the rotenone content of the mixture after 30 days. The reduction was about 40 per cent after 62 days and 50 per cent after 92 days, but no further change was detected even after 12 months.

In the field a bordeaux-cubé combination originally made up to contain 0.02 per cent of rotenone, but which had deteriorated about 50 per cent in rotenone content at the time of application, was tested against the Mexican bean beetle. The combination appeared equal in effectiveness and residual effect to a cube spray containing 0.015 per cent of rotenone.—5-17-41.

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Mr. W. E. McCauley, a graduate of the University of Illinois and for the past seven years a member of the staff of the Illinois State Natural History Survey, has recently resigned to accept a position as manager of the insecticide division of the Velsicol Corporation of Chicago.

Mr. McCauley's new address will be 6118 North Oakley Boulevard, Chicago.

# Application of the Aerosol to Fumigation[1]

## *I. Stabilization of a Naphthalene Aerosol*

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Among the chemicals used as insecticides, only those whose volatility is great enough to produce an effective vapor concentration at ordinary temperatures have been practical as fumigants. In view of this limitation on the use of less volatile compounds, attempts have been made to obtain higher concentrations by some method such as rapid vaporization. In the case of nicotine (Savage 1932), which is extremely toxic to many insects, the application of heat in various ways has been very useful in producing a toxic concentration. With other less toxic substances, such as naphthalene, of which the minimum effective concentration is much higher, something more than just rapid vaporization (Hartzell & Wilcoxon 1930, Whitcomb 1935) is necessary. With many of these materials concentration of the saturated vapor is not enough, and more of the insecticide must be present in the form of an aerocolloid or aerosol.

If insecticides are to be applied in this form, consideration must be given to the properties of aerosols in general and to the specific properties of the one prepared from any chosen insecticide. The stability of an aerosol depends on the size, shape, and uniformity of the particles, the number of particles per unit volume, and the nature of the material forming the particle (Stumpf & Jander 1936, Whytlaw-Gray 1936). The initial size of the particle is dependent entirely on the method of preparation, since no further peptizing (dispersing) action is possible in a gas (Whytlaw-Gray 1936). Particles invariably become larger by collision with and adhesion to other particles or by growth of the particle in contact with its vapor (Thomson 1871). With an aerosol having a vanishingly low vapor pressure, the rate of coagulation is directly proportional to the number of particles in a given volume. Therefore, a very dilute aerosol is more stable than a concentrated one. An aerosol having a measurable vapor pressure will in many cases precipitate very rapidly, because the small particles grow by both processes mentioned above. Sometimes the particles in an aerosol with a high vapor pressure in its saturated atmosphere reach a critical size which is relatively stable. The stabilization is closely related to the type of nuclei on which the particles condense. For example, hygroscopic nuclei produce the most stable fogs (Dobson 1936; Köhler 1936). The presence of an abundance of the proper type of nuclei is very important to the production of a fairly stable aerosol from the condensed vapors of a volatile substance. The previous dispersion of an inert substance furnishing an abundance of nuclei has been suggested by Smirnov & Solntseva (1938).

These facts regarding coagulation might convey the impression that an aerosol is too unstable to be used as a fumigant. Its effective period is much shorter than that of a gas, which does not coagulate at all, but when the time of contact need be only a few hours the stability of a good dispersion may be well within the desired range. Some precipitation may even be advantageous, since it leaves the insect and its habitat covered with the insecticide.

In the first paper of this series (Sullivan *et al.* 1940), describing the use of rotenone and pyrethrum, the toxic material was dispersed in fine particles and practically no vapor of the insecticide was present. In this type of dispersion the aerosol is composed only of the insecticide and is the active part of the system. There is little tendency for growth of crystals and consequent precipitation. When, however, more volatile substances are used with vapor in contact with the dispersed phase, the time required for complete precipitation is very short (Stumpf & Jander 1936). Naphthalene is a good example of this type of material. It can be vaporized easily and it condenses to particles of colloidal dimension, but in a remarkably short time these particles grow to large crystals, which settle completely in a few minutes. Therefore, if this insecticide is to

[1] The authors appreciate the advice and cooperation of C. S. Wilson, of this Bureau.

be used in the form of an aerosol, some method must be devised to prevent its rapid precipitation. In preliminary tests it was found that when naphthalene was vaporized in the presence of an abundance of inert nuclei, its effectiveness increased greatly. A further investigation was made of this observation, where the housefly was used as a biological indicator, and the results are reported in this paper.

MATERIALS AND METHOD.—A sample of naphthalene melting at 80° C. was used in these tests. A burning mixture, which produced a heavy smoke, provided the inert nuclei. This mixture was made by mixing 830 gm. of ground cornstalks with a solution of 170 gm. of sodium nitrate in enough water to wet the cornstalks, and drying overnight in a steam cabinet.

No special apparatus was required for these tests. The naphthalene was boiled off by placing it in an iron pan, 6 inches in diameter and 2 inches high, on a hot plate. The smoke was produced in the chamber by burning the cornstalk-sodium nitrate mixture in an open dish. The enclosure was a reasonably tight Peet-Grady chamber (216 cubic feet), having a small door near the bottom for removing the exposed flies and introducing fresh ones. It was maintained at 29° C. ± 1°. The flies were handled in 10-inch cubical cages with screen wire on the top and two opposite sides. Some of the cages had covers on the top to protect the flies from the naphthalene which settled out directly above this area.

Laboratory-bred flies were used in these tests. From 100 to 200 were placed in each cage. The toxicity tests were conducted in the following manner:

Three cages of flies, one covered and two uncovered, were placed in a Peet-Grady chamber, and 160 gm. of naphthalene was vaporized in about 7 minutes on a hot plate at about 375° C. These cages were exposed for a 20-minute period, and then a second group of three cages was introduced and exposed for the next 30 minutes. In addition a covered cage was introduced after the first 15 minutes and exposed for 35 minutes. At the end of 50 minutes the flies, still in the same cages, were placed in a constant temperature room (28° C.) and fed, and after 24 hours mortality counts were made in the usual manner.

On the same day an identical series of tests were performed in the presence of the smoke, made by burning 20 gm. of the cornstalk-sodium nitrate mixture immediately before the naphthalene was vaporized. These series were repeated, until a maximum of five tests were run, the order of testing with or without smoke being alternated. Two check tests using the smoke alone were also run.

RESULTS.—The mortality data are given in table 1. The results show that the effective period is considerably lengthened when naphthalene is volatilized in the presence of an abundance of inert nuclei.

**Table 1.—Effectiveness against houseflies of vaporized naphthalene with and without smoke. A dosage of 2 pounds of naphthelane per 1,000 cubic feet was used.**[1]

| Exposure, Minutes | Number of Tests | Naphthalene | | Naphthalene and Smoke | |
|---|---|---|---|---|---|
| | | Number of insects | Mortality in 24 hours, per cent | Number of insects | Mortality in 24 hours, per cent |
| Covered: | | | | | |
| 0 –20th | 5 | 762 | 89.9 | 848 | 98.6 |
| 15th–50th | 4 | 557 | 10.0 | 838 | 71.0 |
| 20th–50th | 5 | 1038 | 1.8 | 1174 | 17.2 |
| Uncovered: | | | | | |
| 0 –20th | 5 | 1531 | 99.8 | 1274 | 99.0 |
| 20th–50th | 5 | 2012 | 3.0 | 2060 | 24.4 |

[1] In 2 tests with 1,587 flies exposed to smoke alone in uncovered cages for 35 minutes, the mortality was 1.0 per cent.

These results have been subjected to tests of significance. Before the analysis of variance was made, the percentages were transformed into equivalent angles, a unit of measurement having an independent variance (Bliss 1938). The tests were applied to all classes, including those averaging above 90 and below 10 per cent. While trials were ordered and could be cross-classified by days, the fact that variance for days was substantially the same as for error made it seem admissible to compare variances simply as between and within treatments.

In the test using naphthalene with the inert aerosol for the first period, 0–20 minutes, where the cages were covered, as compared with the test using naphthalene with no aerosol over the same period, the difference approached significance. Also in the case of naphthalene with the inert aerosol for the same period where the cages were uncovered, no difference was detected. Where naphthalene was used with the inert aerosol in covered cages as compared with uncovered cages, no sig-

nificant difference was detected for either the 0–20 minute or the 20–50 minute period. In all other comparisons the differences were real.[1]

The greatest difference was obtained when the cages were covered. The best example of this prolonged efficiency appears in the results for the 15–50 minute period, where the smoke increased the mortality about seven times. It is also noted that the mortality from naphthalene in the presence of inert aerosol was not reduced during the first 20-minute period when the cages were covered, but that a reduction did occur when naphthalene was used alone. Since the mortality from the smoke alone was negligible, these increases in effectiveness are apparently not due to its toxicity.

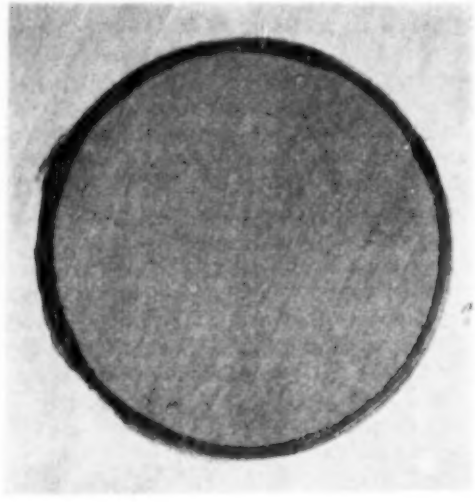

FIG. 1.—Reduction of a naphthalene precipitate on the floor by the presence of smoke. The floor area inside the ring shows deposit when smoke was present; that outside shows the deposit under the same conditions except that no smoke was present.

The mortality results were supplemented by visual examination of the aerosols. When naphthalene is vaporized without smoke, large crystals rapidly form, and the material "snows" out in about 15 to 20 minutes, but when smoke is present condensation appears to take place on the abundant nuclei and the formation of large crystals is greatly retarded. As a result settling is much slower and the deposit is much more evenly distributed over all the surfaces regardless of position.

The effect of the smoke on the amount of material deposited on the floor is shown in figure 1. After a 50-minute exposure to naphthalene volatilized in the presence of smoke, a spot on the floor was covered with an inverted pan, the edges of which were sealed with honey. The rest of the floor was thoroughly cleaned. The same amount of naphthalene was again volatilized with no smoke present. After the same interval the pan was removed and the photograph was taken. The difference was so great that evaporation of the deposit inside the circle was suspected of causing some of the difference, but when the order of test was reversed so that the heavy deposit was inside the circle the same difference was noted.

DISCUSSION.—These experiments show that the presence of an inert aerosol definitely prolongs the effectiveness of naphthalene as measured by its toxicity to the housefly. The aerosol provides a great number of nuclei on which the naphthalene apparently condenses, thus preventing the rapid growth of large, heavy crystals, which would settle rapidly. In this way the saturated vapor in the air is supplemented by suspended insecticide, which is eventually deposited in a well-distributed layer over the insect and the surface on which it resides. In the experiments with the covered cages a better distribution was obtained when an inert aerosol was present. In general practice this might be an advantage, since it would prevent natural obstacles, such as leaves, from protecting the insect against the deposits of the insecticide.

SUMMARY.—Toxicity tests against the housefly were made in the Peet-Grady chamber, in which naphthalene was vaporized both alone and in the presence of smoke from a burning mixture containing cornstarch and sodium nitrate. The effective period of dispersed naphthalene was greatly lengthened by vaporization in the presence of the smoke. This increased effectiveness seems to be due to adsorption of the insecticide on the inert particles. The presence of the inert particles changes the character of the deposit and the rate of crystallization, as well as the size of the crystal. Instead of being collected mostly on the floor, the

[1] The authors are indebted to F. M. Wadley, of this Bureau, for assistance in this statistical treatment.

naphthalene was deposited more uniformly on all surfaces regardless of position. The difference in mortality between the lots of flies exposed to naphthalene with and without smoke was greater in covered than in open cages.—5-31-41.

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# The Revival of Cigarette Beetle Larvae Fumigated with Hydrocyanic Acid

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The time that should elapse between fumigation treatment and mortality determination is dependent on many factors, among the most important being the nature of the toxicant and the susceptibility of the insect species.

Tests were made to determine the revival from day to day of larvae of the cigarette beetle, *Lasioderma serricorne* (F.), following fumigation with various concentrations of hydrocyanic acid gas for different exposure periods. The purpose of this paper is to bring out the rate at which revival of treated larvae occurred. These data indicate in some measure the time, following treatment of test larvae, when the percentage of mortality should be determined.

REVIEW OF LITERATURE.—It is apparent from the literature that variation occurs among insect species in revival from day to day after fumigation with hydrocyanic acid gas and that investigators have followed no definite procedure when determining the time that should elapse before mortality counts are made. Therefore comparison of the results of different workers can be made only with considerable difficulty.

Strand (1930), working with adults of *Tribolium confusum* Duv., found that little or no change in mortality occurred after a post-fumigation period of 24 hours.

Ginsburg (1933), using codling moth larvae as test insects, found that some individuals which were apparently dead at the end of the fumigation period revived after being exposed to the air for several hours, and he based his mortality determinations on observations made at the end of 24 hours.

Brindley & Baker (1927) fumigated *Aphis rumicis L.*, *Sitophilus oryzae* (L.), and *S. granaria* (L.) and kept them overnight at a constant temperature before determining mortality.

Swain (1918) found that adults of *Hippodamia convergens* Guer. were either dead

or recovered "within a comparatively few hours after fumigation."

In working with *Drosophila melanogaster* Meig. Bliss & Broadbent (1935) observed that flies showing a mortality of 15 per cent immediately after fumigation showed a mortality of 50 per cent 2 days later.

Peters & Ganter (1935), in a study of the toxicity of hydrocyanic acid gas to *Sitophilus granaria*, found that immediately following fumigation the beetles were motionless. Observations were made for 7 days, and only individuals that had shown no sign of life during this period were regarded as having been killed by the fumigant. Those insects that had revived but were moribund or dead at the end of the 7 days, as well as those still living, were recorded as having survived the fumigation.

Hamlin & Reed (1927), in fumigation tests with carbon disulfide under commercial conditions, showed that in general insects exhibited progressive revival following fumigation until the maximum was reached, after which mortality became evident. They suggested that the percentage of kill be based on maximum revival. Since their investigations were not executed under controlled conditions and did not include a study of the factors which may affect the revival from day to day, no definite conclusions were made, but it was their belief that "maximum revival, or minimum kill," was "the most satisfactory index of effectiveness."

Later Allison (1928), in studying the toxicity of hydrocyanic acid gas to *Periplaneta americana* (L.), *Sitophilus oryzae*, and the albino rat, followed the same method.

METHODS AND APPARATUS.—The apparatus consisted of a flowmeter, hydrocyanic acid gas generators, fumatorium, absorption bottles, and suction apparatus. These were connected with glass tubing in the order named in such a way that air entered the flowmeter, where its volume was measured, passed next through the generators, where hydrocyanic acid gas was taken up, then to the fumatorium containing the insect material, then through the absorption or sampling bottle, where the fumigant was recovered, and finally to the suction apparatus. The concentration of hydrocyanic acid gas in the air stream was determined by the Leibig method as given by Scott (1925).

Full-grown larvae of the cigarette beetle were exposed to hydrocyanic acid gas at concentrations of 5, 10, and 15 milligrams per liter for 1, 2, and 3 hours.

In previous experiments[1] it had been found that complete mortality resulted when larvae were exposed to 5 milligrams of hydrocyanic acid gas per liter for 8 hours, to 10 milligrams per liter for 5 hours, or to 15 milligrams per liter for 4 hours. Therefore, with the concentrations and exposures used in the present experiments it was possible to study the day-to-day revival when mortality was low and when it was nearly complete.

The method of rearing cigarette beetle larvae has been described by Livingstone

[1] Unpublished manuscript by E. M. Livingstone and L. B. Davis.

**Table 1.—Revival of larvae of the cigarette beetle fumigated with various concentrations of hydrocyanic acid gas for different exposure periods, Richmond, Va., 1937.**

| Hours of Exposure | Milligrams of Gas per Liter | Number of Larvae | Percentage of Larvae Found Revived on Indicated Day Following Treatment[1] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | First | Second | Third | Fourth | Fifth | Sixth | Seventh |
| 1 | 5 | 50 | 52.0 | 82.0 | **86.0** | 84.0 | 82.0 | 78.0 | 78.0 |
| | 10 | 100 | 28.0 | 51.0 | 58.0 | **60.0** | 56.0 | 56.0 | 56.0 |
| | 15 | 200 | 14.0 | 26.5 | 33.0 | **34.5** | 34.0 | 32.5 | 28.5 |
| 2 | 5 | 100 | 25.0 | 53.0 | **64.0** | 61.0 | 60.0 | 61.0 | 59.0 |
| | 10 | 250 | 1.6 | 6.0 | 11.6 | 13.6 | **14.0** | 13.6 | 12.8 |
| | 15 | 300 | .7 | 5.0 | 9.0 | 11.3 | **11.7** | 11.3 | 10.3 |
| 3 | 5 | 150 | 5.3 | 26.7 | 36.7 | **37.3** | 37.3 | 37.3 | 37.3 |
| | 10 | 250 | 1.2 | 2.8 | 8.4 | 11.6 | **12.0** | 11.6 | 12.0 |
| | 15 | 350 | 0.0 | .9 | 2.0 | 2.3 | **2.6** | 2.3 | 1.7 |

[1] Figures in bold-faced type indicate maximum revivals.

*et al.* (1936). In brief, the larvae were fed on corn meal and kept in a room in which the temperature was maintained at about 82° F. and the relative humidity between 65 and 70 per cent. The fumigations were conducted at a temperature of 82° and at normal atmospheric pressure. After fumigation the insects were kept in a laboratory in which the temperature and relative humidity fluctuated around normal, namely, 70° to 82° F. and 50 to 70 per cent, respectively.

The insects were held under observation for 7 days, since preliminary experiments[2] at the dosages tested had shown that all revival to be expected occurs within this time. At the end of the 7-day period there was no doubt as to whether the insects were dead or alive. Those alive had recovered sufficiently to show movement and those dead showed definite signs of hardening or decomposition or both.

RESULTS.—The revival of larvae of the cigarette beetle from day to day following the different fumigation treatments is shown in table 1.

For each exposure period there was a gradual decrease in larval revival as the concentration of the gas increased, and for each concentration of gas there was a gradual decrease in revival as the length of exposure increased.

Larval revival increased gradually from day to day until the point of maximum revival was reached, and after that there appeared to be little or no relation between revival and time following fumigation.

DISCUSSION AND CONCLUSIONS.—The results of these experiments show that the length of time the insects were exposed to hydrocyanic acid gas, as well as the concentration of the gas, affected the day-to-day revival of the cigarette beetle after treatment. Therefore, if more than one exposure or more than one concentration has been used, the selection of an arbitrary time after fumigation for determining mortality is likely to lead to error. Especially is this true when both different exposures and different concentrations have been used.

Whether or not revival is progressive with all fumigants and with all species of insects remains to be determined.

When different concentrations of hydrocyanic acid gas for different exposure periods are to be tested against larvae of the cigarette beetle, the percentage of kill for each concentration and exposure should be determined on the day maximum revival occurs. Moreover, the use of maximum revival as a basis for determining mortality would lead to conservative results. This statement is based on the thesis that all mortality occurring before maximum revival, or at least the greater part of it, is due to the effect of the fumigant, whereas all mortality occurring after maximum revival, or at least most of it, is due to natural causes.

Considerable differences in day-to-day revival have been observed between insects fumigated at atmospheric pressure and those fumigated in a partial vacuum. For example, cigarette beetle larvae fumigated with sublethal dosages of a mixture of ethylene oxide (1 part) and carbon dioxide (9 parts) in a partial vacuum exhibited greater revival immediately following fumigation than at any other time. The movements of the larvae were not normal, but appeared to be spasmodic, and upon examination on following days it was usually found that there was a decrease in the number of larvae showing such movements. This period of activity was then usually followed by another, during which the insects gradually resumed activity until a maximum revival was indicated, although this maximum was below that previously attained. Thereafter the number of survivors remained constant or gradually decreased. The first peak of activity was believed to be due to the slow action of this particular gas, its toxic effect not being sufficient at that time to kill the insects. The surcease of action as time progressed indicated that there was a cumulative effect.

No doubt, however, some fumigants, under certain conditions, will produce maximum revival immediately following treatment.—6-21-41.

[2] Unpublished data.

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# Sulfur as a Stomach Insecticide[1]

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Elemental sulfur is well known as a fungicide and as a contact insecticide and fumigant. The authors wish to present in this paper results of insecticidal tests as indications that sulfur may also have limited use as a stomach poison.

So far as can be ascertained, only MacLeod (1937) has published on sulfur as a stomach insecticide. He reported that ingestion of sulfur by the eastern tent caterpillar, *Malacosoma americana* (F.), resulted in a high mortality of that insect. In correspondence MacLeod informed the writers that similar results had been obtained with the yellow mealworm, *Tenebrio molitor* (L.), and with cockroaches. At Cornell, E. M. Stafford also made an extensive study of the effect of sulfur on the eastern tent caterpillar and yellow mealworm. It is understood that he observed the same toxic effect but as yet his results have not been published.

**Table 1.—Relation of concentration or charge to deposit.**

| SPRAY APPLICATION | | DUST APPLICATION | |
|---|---|---|---|
| Concentration[1] | Deposit | Charge | Deposit |
| *gm./liter* | *mg./cm.²* | *mg.* | *mg./cm.²* |
| 8.2 | 0.02 | 20 | 0.040 |
| 16.5 | 0.04[2] | 50 | 0.100 |
| 41.3 | 0.10 | 100 | 0.200 |
| 123.8 | 0.30 | 200 | 0.400 |

[1] Volume sprayed was 1.2 cc.
[2] A deposit of 0.04 mg./cm.² approaches very closely the deposit that would be expected in the field upon application of a spray made up to the strength of three pounds to one hundred gallons.

In the summer of 1939 laboratory tests were conducted by the writers with several brands of sulfur, against last instar forms of a number of species of insects. All species with the exception of the catalpa sphinx, *Ceratomia catalpae* (Bdv.) and the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), were reared in a specially built rearing room in which temperature and humidity were relatively constant (Waters 1937). The catalpa sphinx larvae were collected in the field and the Colorado potato beetle larvae were reared in a greenhouse.

METHODS.—All tests were conducted quantitatively using methods developed by H. A. Waters (to be published). Essentially these methods were as follows: Known doses of sulfur were sprayed or dusted into a celluloid cylinder in the bottom of which were the leaves and weighing plate being used for any particular test. As the resulting deposit over the base of the cylinder was relatively uniform, the weight of insecticide per unit area of leaf surface was determined by reweighing the plate. Table 1 gives examples of deposits obtained with different concentrations of sprays and charges of dust.

The treated leaves were placed individually in open top screen cages, each leaf being inserted in a vial of water to prevent wilting. A strip of celluloid coated with a thin film of vaseline around the upper border of the cage prevented the escape of the larvae (Fig. 1). A single larva to a cage was used in every case excepting

[1] The authors wish to acknowledge their appreciation of the assistance of Dr. F. L. Campbell and Dr. D. M. DeLong of the Department of Entomology.

tests involving the Mexican bean beetle, *Epilachna varivestis* (Muls.) and the Colorado potato beetle where two larvae were used (Fig. 2).

Daily records of mortality and amount of food eaten were taken over a period of three days. At the end of this period mortality counts were made. Moribund insects were called dead.

RESULTS.—The salt marsh caterpillar, *Estigmene acraea* (Drury); fall webworm, *Hyphantria cunea* (Drury); Mexican bean beetle and Colorado potato beetle fed on leaves bearing a deposit of 0.4 mg./cm.$^2$ (equivalent to that obtained by spraying 30 lbs. of sulfur/100 gal.) without any mortality. Catalpa sphinx larvae were unaffected by feeding on a deposit of 0.1 mg./cm.$^2$ (7.5 lbs./100 gal.).

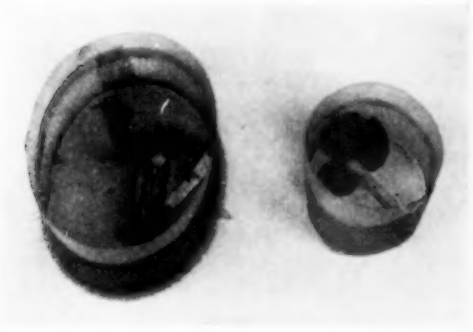

FIG. 1.—Cages used for gross feeding tests of (1) southern armyworm and (2) Colorado potato beetle larvae.

The southern armyworm, *Prodenia eridania* (Cram.); variegated cutworm, *Lycophotia margaritosa saucia* Hbn.; and fall armyworm, *Laphygma frugiperda* (S. & A.) were noticeably affected by sulfur ingestion. The results of the tests on these species are summarized in tables 2 and 3.

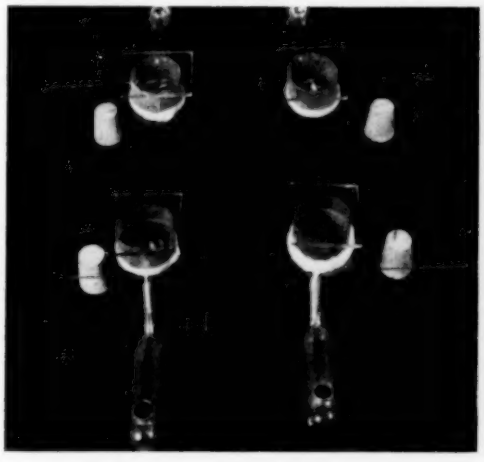

FIG. 2.—Cages used for gross feeding tests of Mexican bean beetle larvae.

In all cases ingestion of a lethal dose of sulfur by the southern armyworm produced characteristic symptoms. Twelve hours after feeding the larvae were inactivated and at the end of 24 hours they were apparently constipated. During this period they regurgitated a bluish-black fluid.

**Table 2.—Effect of different brands of sulfur applied as a dust and ingested by the last instar of the southern armyworm.**

| SAMPLE OF SULFUR | TEST INSECT | NO. INSECTS TESTED | CHARGE | DEPOSIT | SULFUR CONSUMED PER LARVA | MORTALITY |
|---|---|---|---|---|---|---|
| | | | *mg.* | *mg./cm$^2$* | *mg.* | *per cent* |
| Dusting Sulfur (A) | Southern armyworm | 14 | 50 | 0.108 | 1.0 | 64 |
| | | 8 | 200 | 0.368 | 1.5 | 100 |
| | | 8 | 400 | 0.812 | 1.5 | 100 |
| Dusting Sulfur (B) | Southern armyworm | 7 | 50 | 0.100 | 1.0 | 71 |
| Flowers of Sulfur | Southern armyworm | 8 | 50 | 0.128 | 1.0 | 75 |
| Wettable Sulfur (C) | Southern armyworm | 20 | 65 | 0.116 | 1.0 | 85 |
| | | 40 | 50 | 0.089 | 1.0 | 92 |
| | | 50 | 100 | 0.202 | 1.2 | 96 |
| Dusting Sulfur (A) | Variegated cutworm | 7 | 50 | 0.096 | 1.0 | 0 |
| | | 15 | 100 | 0.208 | 1.2 | 46 |
| | | 6 | 200 | 0.368 | 1.5 | 83 |

On the second day it was observed that some larvae exuded a colorless to slightly yellow liquid from the anus. These larvae usually died. Moribund insects became discolored in various regions of the body, and after death these regions blackened (Fig. 3). In contrast to the flaccid condition of larvae killed by arsenic, the bodies of larvae killed by sulfur became turgid and remained so after death. This turgidity seemed more pronounced in larvae that had fed on dusted sulfur than in those that had fed on sprayed sulfur.

Long after all signs of life ceased in the head and midsection, the posterior end of the abdomen still responded to stimuli.

Dissection and microscopic examination of the gut contents of these larvae showed sulfur particles as small yellow specks. Such particles were not seen in untreated checks, but to be sure that they were sulfur particles, the midgut contents were extracted with carbon disulfide, the solution filtered and allowed to crystallize. Definite sulfur crystals were found. Observations on passage of sulfur through the gut are given in table 4.

**Table 3.—Effect of wettable sulfur (C) applied as a spray.**

| No. of insects used in tests | Concentration of suspension | Deposit | Average quantity of sulfur consumed per larva | Mortality Per Cent |
|---|---|---|---|---|
| | *gm./liter* | *mg./cm.²* | *mg.* | *per cent* |
| **Southern Armyworm** | | | | |
| 70 | 20 | 0.05 | 0.8 | 2.5 |
| 104 | 40 | 0.10 | 1.1 | 41.0 |
| 50 | 80 | 0.20 | 1.2 | 94.0 |
| 20 | 120 | 0.30 | 1.5 | 100.0 |
| **Fall Armyworm** | | | | |
| 20 | 80 | 0.16 | 1.5 | 20.0 |

**Table 4.—Passage of sulfur through gut of southern armyworms feeding on a deposit of approximately 0.1 mg./cm.²**

| Duration of Feeding Hours | Number of Insects Examined | Progress of Sulfur |
|---|---|---|
| 1 | 4 | Forepart of midgut |
| 2 | 4 | 2/3 through midgut |
| 3 | 4 | Near pyloric valve |
| 4 | 4 | Near pyloric valve |
| 5 | 4 | Near pyloric valve |
| 6 | 4 | Near pyloric valve |

When the sulfur reached the region of the pyloric valve, it formed small lumps mixed with leaf tissue. These aggregations of particles were not large enough to obstruct the passage at this point yet they were not observed to pass beyond the pyloric valve.

The intestinal wall near the insertion of the Malpighian tubes was discolored. This discoloration began as a thin black band which widened anteriorally and posteriorally until the hind gut and about one half the midgut was totally black. The extent of the discoloration depended on the quantity of sulfur consumed The Malpighian tubes seemed flatter than normal.

Fig. 3.—Southern armyworms that died as a result of sulfur ingestion.

Discussion.—It was shown in the preceding section that commercial sulfur is toxic when ingested by certain larvae. The southern armyworm was susceptible to four different brands, all presumably consisting of sulfur of high purity. However, the possibility remains that traces of impurities may have been responsible for the toxic effects, or if sulfur itself is the toxic

agent, its toxicity might be attributed to certain allotropic forms. The following samples of sulfur were therefore prepared and tested to shed some light on this question:

Sample No. 1: A pure crystalline sulfur obtained by fractional distillation of crystalline sulfur in a high vacuum Hickman still. This product, representing the middle third of the solidified distillate, was ground in a ball mill to a particle size of about 40 microns.

Sample No. 2: Same as No. 1 except that impurities were added (0.013 per cent each of $Ag_2SO_4$, $NiSO_4$ and $CuSO_4$) by grinding in a ball mill as above.

Sample No. 3: Residue from distillation of No. 1. Ground as above.

Sample No. 4: Residue of amorphous sulfur insoluble in carbon disulfide, obtained by filtration of a mixture of commercial sulfur and carbon disulfide. This product did not need grinding as it was more finely divided than the other three.

These four samples were tested in parallel as dusts against the southern armyworm. Only sample No. 4 caused mortality on the order of that produced by the commercial samples in table 3. The others, ranging in deposit from 0.06 to 0.236 mg./cm.$^2$, had little or no effect on the larvae. These preliminary tests did not explain the toxicity of commercial sulfurs as stomach insecticides, but suggest three possibilities for further investigations: (1) As sample No. 4 was more finely divided than the others, toxicity of sulfur as a stomach insecticide may be related to particle size, (2) amorphous sulfur, insoluble in carbon disulfide, may be inherently more toxic than crystalline sulfur, soluble in carbon disulfide, (3) the amorphous sulfur may contain unidentified impurities that are responsible for its toxic effect.

SUMMARY.—In laboratory tests of commercial powdered sulfur applied as a spray or dust to foliage and ingested by last instar larvae of several species of leaf-eating insects, it was found that sufur may be lethal to the southern armyworm, the variegated cutworm, and the fall armyworm. It was not toxic at high doses to the catalpa sphinx, the salt marsh caterpillar, the fall webworm, the Mexican bean beetle and the Colorado potato beetle.

Because the southern armyworm was the most susceptible to commercial sulfur of all species used, most of the tests were made with this species. Lethal doses produced characteristic symptoms within a few hours; *i.e.*, inactivation, constipation and regurgitation followed after death by blackening of part of the body, which remained turgid.

The toxic action of commercial sulfur as a stomach insecticide is not understood. A few tests on special fractions of sulfur against the southern armyworm, suggested the desirability of further investigations on relations among particle size, allotropic form and toxicity of pure sulfur. —5-31-41.

## LITERATURE CITED

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**Waters, H. A.** 1937. Methods and equipment for laboratory study of insecticides. JOUR. ECON. ENT. **30**: 179–204.

## EASTERN BRANCH TO MEET IN BALTIMORE

The Eastern Branch of the American Association of Economic Entomologists will hold its annual meetings in Baltimore, Maryland, on November 13 and 14, 1941.

Headquarters will be in the Lord Baltimore Hotel where the meetings will also be held.

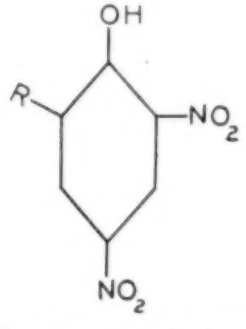
Visiting entomologists will receive a cordial welcome and enjoy an interesting program.

# The Relative Toxicity of Some 2,4-Dinitro-6-R-Phenols[1]

J. F. Kagy,[2] *University of California Citrus Experiment Station, Riverside*

In studies of numerous nitrated phenols, it has become apparent that the 2,4-dinitro-6-alkylphenols and cycloalkylphenols possess relatively higher toxicity to insects and mites than some of their closely related isomers. Because of the practical significance to economic entomology of several of these nitrated phenols, it has been considered worth while to present certain information concerning the relative toxicity of some members of this group of compounds to insects and mites.

The number of possible 2,4-dinitro-6-R-phenols is, of course, theoretically unlimited; therefore only compounds of particular interest will be discussed, namely, those having the general structural formula




in which R represents a hydrogen or certain alkyl or alicyclic groups. The 2,4-dinitro-6-arylphenols, such as 2,4-dinitro-6-phenylphenol, have not been shown to possess appreciable toxicity to insects (Kagy 1936).

Literature.—Some of these 2,4-dinitro-6-R-phenols have been known to economic entomology since 1892, when a mixture containing potassium 3,5-dinitro-*o*-cresylate was marketed as an insecticide.[3] The original workers in Germany were probably aware that 3,5-dinitro-*o*-cresol (2,4-dinitro-6-methylphenol) was more toxic to insects than 2,4-dinitrophenol, inasmuch as the latter was well known at that time. However, Tattersfield *et al.* (1925), in studies with *Aphis rumicis* L. and with eggs of *Selenia tetralunaria* Hufn., were apparently the first to record quantitatively that 3,5-dinitro-*o*-cresol was more toxic than 2,4-dinitrophenol.

Kagy (1936) determined that the lead salt of 2,4-dinitro-6-cyclohexylphenol was more toxic as a stomach poison to the corn ear worm, *Heliothis armigera* (Hbn.), than the lead salt of 3,5-dinitro-*o*-cresol. Shaw & Steer (1938) made a comprehensive study of the relative toxicity of 2,4-dinitrophenol and 3,5-dinitro-*o*-cresol, in the laboratory and field, to eggs of several species of insects. They confirmed the findings of Tattersfield *et al.* (1925): that 3,5-dinitro-*o*-cresol was much more toxic than 2,4-dinitrophenol to insect eggs. Bushland (1940), in toxicity studies with young screwworms, *Cochliomyia americana* C. and P., determined that 2,4-dinitrophenol and its sodium salt were less toxic than 3,5-dinitro-*o*-cresol and its sodium salt. Bushland reported that 3,5-dinitro-*o*-cresol and 2,4-dinitro-6-cyclohexylphenol were in a minimum lethal concentration range of 0.01 to 0.03 per cent and noted that 2,4-dinitro-6-cyclohexylphenol was not tested below 0.03 per cent.

In a laboratory study of the effectiveness of various materials on the greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouché), Bartlett & Persing[4] made a direct comparison between 2,4-dinitro-6-cyclohexylphenol and 3,5-dinitro-*o*-cresol against the eggs of this species. The compounds were dissolved in a highly refined light-medium petroleum oil which was emulsified in a spray at a concentration of 0.5 per cent. The spray which contained 2,4-dinitro-6-cyclohexylphenol at a concentration of 0.5 per cent by weight of the oil gave a net mortality of 94.1 per cent. In contrast, the spray which contained 3,5-dinitro-*o*-cresol at a concentration of 1 per cent by weight of the oil afforded a net mortality of zero.

This resume of the literature is not exhaustive, only those papers in which there has been a quantitative estimation of the toxicity differences of this class of nitrated

[1] Paper No. 435, University of California Citrus Experiment Station, Riverside, California.

[2] Research Fellow in Entomology in the Experiment Station.

[3] German Patent No. 74,097 and British Patent No. 3,301.

[4] To be published in December in the Journal of Economic Entomology.

phenols having been reviewed. Of interest is the fact that previous workers in tests with many species of insects agree that 3,5-dinitro-*o*-cresol is more toxic than 2,4-dinitrophenol.

PHYSICAL AND CHEMICAL PROPERTIES OF THE COMPOUNDS.—The organic chemicals considered in this paper are too numerous to allow a comprehensive discussion of their physical and chemical properties. Furthermore, this information, together with methods of synthesis is readily available in the chemical and patent literature.[1]

In general, the chemistry of the 2,4-dinitro-6-R-phenols is very similar, particularly among the homologues, but the physical properties vary considerably. At 20° C., some of the phenols are pale-yellow crystalline solids; others are amber-colored viscous oils, which, with slight impurities, may be reddish brown.

The important physical and chemical properties of 2,4-dinitro-6-cyclohexylphenol have been discussed by Boyce *et al.* (1939a) in relation to the control of certain insects and mites. Much of the material presented in that paper may be applied as relevant in a general way to the series of 2,4-dinitro-6-R-phenols. It should be pointed out, however, that even minor variations in the physical and chemical properties of members of this class of compounds are factors limiting their usefulness as insecticides. At the present time many of these phenols are chemical curiosities and of academic interest only. Since these organic chemicals[2] melted or boiled within a narrow range of temperatures, they were reasonably pure.

STUDIES WITH THE COMPOUNDS AS STOMACH POISONS FOR INSECTS.[3]—Data on the toxicity of these phenols as stomach poisons for insects are presented. The values were determined by the sandwich method (Campbell & Filmer 1929; Stellwaag 1931), but the technique used and the procedure followed were suggested by Hansberry & Richardson (1936).

The sandwich method requires that the chemical be applied to single-leaf discs in the form of a dust. Whenever possible, the unadulterated chemical was employed. Many of the compounds, however, were such that they could not be readily dusted; and many were so toxic that measurable lethal deposits could not be accurately ascertained without first dispersing the compound in an appropriate diluent. A good grade of calcined diatomaceous earth was a satisfactory diluent.

The compounds were mixed with this diluent at ratios dependent upon their physical properties and toxicities. The liquid compounds were uniformly dispersed in the diluent. The crystalline solids were mechanically mixed with the diluent and carefully heated, with constant mixing, to the melting point of the compound. The mixture was subsequently allowed to cool and then comminuted.

All insect larvae used in these tests were of the fifth instar. Previous workers employing the silkworm, *Bombyx mori* L., as a test insect have used fourth-instar larvae. But many of the phenolic compounds are rather repellent, and fourth-instar larvae of this insect frequently cause considerable trouble and prefer to molt prematurely rather than consume the poisoned leaf disc. The use of fifth-instar larvae approximately 24 hours after the molt overcame this difficulty to some extent, the more mature larvae being so much more ravenous. Also, a more accurate determination of the dosage per unit weight was made possible by the use of the heavier larvae. Determination of the median lethal doses of acid lead arsenate, rotenone, and 2,4-dinitro-6-cyclohexylphenol to both fourth- and fifth-instar silkworms did not reveal a real difference in susceptibility.

The relative toxicity to the silkworm of some 2,4-dinitro-6-R-phenols was determined. A summary of the data is presented in table 1. Each dosage range of the intermediate zone is delimited by the lowest lethal and highest nonlethal dose. Values for the median lethal doses, with which there is an equal chance for death and recovery, are also recorded.

There is a progressive increase in toxicity of the 2,4-dinitro-6-alkylphenols with an increase in the length of the normal alkyl chain up to six and seven carbon atoms. Both 2,4-dinitro-6-*n*-hexylphenol

[1] United States Patents Nos. 1,880,404 and 2,048,168.

[2] All organic chemicals considered, with the exception of rotenone, were prepared in the Organic Research Laboratories of The Dow Chemical Company, Midland, Michigan.

[3] These studies were conducted under the direction of C. H. Richardson at Iowa State College, Ames, Iowa. Cass F. Smith, J. H. Cochran, N. P. Larson, and Charles Apple, assisted at intervals during the years 1934 to 1937, and their valuable aid is acknowledged. The project was carried out under the auspices of the Crop Protection Institute, with funds provided by The Dow Chemical Company of Midland, Michigan.

and 2,4-dinitro-6-*n*-heptylphenol were more toxic than the lower members of the homologous series. The first member of the series, 3,5-dinitro-*o*-cresol (2,4-dinitro-6-methylphenol), was the least toxic. Since there is very little overlapping of the intermediate zone ranges, the differences among the values for the median lethal doses are highly significant. An increase in carbon atoms above seven in the alkyl chain resulted in a decrease of toxicity: 2,4-dinitro-6-*n*-octylphenol was less toxic than 2,4-dinitro-6-*n*-heptylphenol and was about equal in toxicity to 2,4-dinitro-6-*n*-butylphenol.

**Table 1.—The relative toxicity of some 2,4-dinitro-6-R-phenols to fifth-instar larvae of the silkworm, *Bombyx mori* L.**

| Compound | Dosage Range of Intermediate Zone | Median Lethal Dose |
|---|---|---|
| | Milligrams per Gram of Larva | |
| Acid lead arsenate | 0.060–0.119 | 0.090 |
| Rotenone | 0.002–0.004 | 0.003 |
| 3,5-Dinitro-*o*-cresol (2,4-dinitro-6-methylphenol) | 0.030–0.072 | 0.049 |
| 2,4-Dinitro-6-ethylphenol | 0.017–0.057 | 0.029 |
| 2,4-Dinitro-6-*n*-propylphenol | 0.011–0.027 | 0.018 |
| 2,4-Dinitro-6-*n*-butylphenol | 0.008–0.011 | 0.009 |
| 2,4-Dinitro-6-*n*-pentylphenol | 0.007–0.009 | 0.008 |
| 2,4-Dinitro-6-*n*-hexylphenol | 0.003–0.006 | 0.004 |
| 2,4-Dinitro-6-*n*-heptylphenol | 0.003–0.005 | 0.004 |
| 2,4-Dinitro-6-*n*-octylphenol | 0.007–0.014 | 0.010 |
| 2,4-Dinitro-6-cyclopentylphenol | 0.007–0.012 | 0.009 |
| 2,4-Dinitro-6-cyclohexylphenol | 0.004–0.012 | 0.007 |
| Dinitrothymol (2,4-dinitro-3-methyl-6-*iso*propylphenol) | 0.028–0.041 | 0.033 |

Among the 2,4-dinitro-6-cycloalkylphenols studied were 2,4-dinitro-6-cyclohexylphenol and 2,4-dinitro-6-cyclopentylphenol. 2,4-Dinitro-6-cyclohexylphenol was less toxic to the silkworm than 2,4-dinitro-6-*n*-hexylphenol or 2,4-dinitro-6-*n*-heptylphenol, but was a little more toxic than some other members of the homologous series of dinitro-6-alkylphenols. The 2,4-dinitro-6-cyclohexylphenol was more toxic to the silkworm than its homologue, 2,4-dinitro-6-cyclopentylphenol. This same relationship of toxicity holds for larvae of the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), and for larvae of the painted lady, *Cynthia cardui* (L.) (table 2). It is of academic interest to note that dinitrothymol (2,4-dinitro-3-methyl-6-*iso*-propylphenol), in spite of the additional alkyl group on the benzene ring, was about as toxic to the silkworm as 2,4-dinitro-6-ethylphenol, but was less toxic than 2,4-dinitro-6-*n*-propylphenol.

All the 2,4-dinitro-6-alkylphenols and cycloalkylphenols are more toxic to the silkworm than acid lead arsenate but less toxic than rotenone. The two dinitro-cycloalkylphenols were more toxic than acid lead arsenate to larvae of the Colorado potato beetle and *Cynthia cardui*. On the other hand, the two nitrated phenols were less toxic than rotenone to larvae of the potato beetle and were more toxic than rotenone to larvae of *C. cardui*. A further discussion of the relative toxicity of 2,4-dinitro-6-cyclohexylphenol and several well-known stomach poisons to several species of lepidopterous larvae may be found in papers by Kagy (1936) and by Hansberry & Richardson (1936).

SPEED OF TOXIC ACTION.—Since the silkworm larvae were not continuously observed for death, survival-time data corresponding to each dosage of the many compounds administered orally to these insects were estimated. The quantity of these data for any one compound was in most instances too meager for statistical treatment. The data available on 2,4-dinitro-6-cyclohexylphenol were ade-

**Table 2.—Median lethal doses of some compounds determined on fifth-instar larvae of the painted lady, *Cynthia cardui* (L.), and of the Colorado potato beetle, *Leptinotarsa decemlineata* (Say).**

| Compound | Colorado Potato Beetle | | Painted Lady[1] | |
|---|---|---|---|---|
| | Dosage Range of Intermediate Zone | Median Lethal Dose | Dosage Range of Intermediate Zone | Median Lethal Dose |
| | (In Milligrams per Gram of Larva) | | | |
| Acid lead arsenate | 0.055–0.115 | 0.080 | 0.140–0.190 | 0.160[2] |
| Rotenone | 0.001–0.004 | 0.002 | 0.021–0.072 | 0.030[2] |
| 2,4-Dinitro-6-cyclohexylphenol | 0.007–0.025 | 0.016 | 0.014–0.030 | 0.020 |
| 2,4-Dinitro-6-cyclopentylphenol | 0.015–0.030 | 0.021 | 0.039–0.077 | 0.050 |
| Dinitro-α-naphthol | — | — | — | >0.294 |

[1] Tests made during July, 1935, on fifth-instar larvae collected in the field.
[2] Determined by Hansberry & Richardson (1936).

quate, however, because hundreds of larvae were fed doses of the compound. Mean survival-time data for a series of dosage-range groups have been entered in table 3.

The mathematical relation between dosage and survival-time data is recognized as hyperbolic in character. It was assumed, therefore, that a hyperbolic function of the equilateral type in accordance with the equation $xy=k$, where $x$ is the dosage, $y$ is the survival time, and $k$ is a constant, would apply. Within each dosage range (Table 3) a sum of products of the two variables was computed. The mean for the products has been entered in table 3 as the statistic $k$, and is referred to as the toxicity constant. The $k$ values for the dosage ranges vary, those for the extreme ranges being larger than those for the midranges. Statistical analysis shows that for the midranges in the region of the vertex, the toxicity constants 0.058, 0.067, and 0.062 are alike, but that these differ significantly from the constants for the extremes of the ranges. Over the entire dosage range a hyperbolic equation cannot hold. For the mid-ranges an equation does apply, and this has been calculated to be $xy=0.063$.

**Table 3.—The toxicity of 2,4-dinitro-6-cyclohexylphenol to fifth-instar larvae of the silkworm, *Bombyx mori* L., and the relation between dosage and survival time.**

| Dosage Range | Mean Dosage | Mean Survival Time, in Hours | Toxicity Constant, $k$ |
|---|---|---|---|
| Milligrams per Gram of Larva | | | |
| 0.040–0.100 | 0.056 | 1.77 | 0.104 |
| 0.030–0.039 | 0.035 | 1.63 | 0.058 |
| 0.020–0.029 | 0.025 | 2.76 | 0.067 |
| 0.010–0.019 | 0.014 | 4.87 | 0.062 |
| 0.004–0.009 | 0.007 | 14.20 | 0.106 |

The dosage-time-survival curve for 2,4-dinitro-6-cyclohexylphenol, and the hyperbolic equation are plotted in figure 1. The reasons why the equation does not hold at higher dosages and survival times are apparent, inasmuch as high lethal doses of the poison do not produce death in a correspondingly short time, and low lethal doses tend to cause larvae to linger moribund beyond the normal time for expectancy of death. Richardson & Seiferle (1939) have shown in experiments with the two-striped grasshopper, *Melanoplus bivittatus* (Say), that the dosage-time-survival curves for several poisons flattened at high dosages because survival time tended to become independent of dosage.

Curves showing the speed of toxic action for 2,4-dinitro-6-methylphenol and

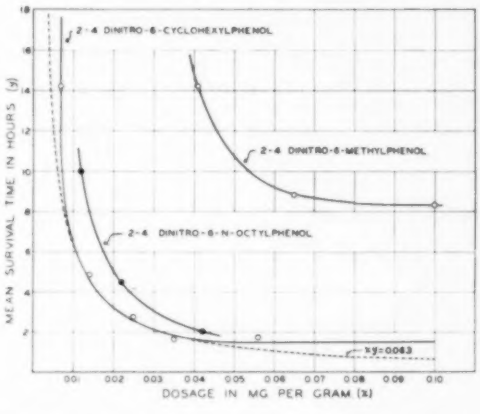



FIG. 1. Curves showing the toxicity of some 2, 4-dinitro-6-R-phenols to fifth-instar silkworm larvae and the relation between dosage and survival time.

2,4-dinitro-6-*n*-octylphenol are shown in figure 1. These curves are mathematically similar to that for 2,4-dinitro-6-cyclohexylphenol, and the positions of their vertexes correspond to their relative toxicities to the silkworm. The dosage at the vertex of each curve might be termed the true lethal dosage, because at lower dosage values, the curve is moving in the direction of survival for the normal span of the insect's life.

RELATIVE TOXICITY IN PETROLEUM-OIL SOLUTIONS.—Kagy & Richardson (1936) published data and curves on the toxicity of petroleum-oil solutions of 2,4-dinitro-6-cyclohexylphenol to the San Jose scale, *Aspidiotus perniciosus* Comstock, and to eggs of *Lygaeus kalmii* Stål. Utilizing the exact methods of this work, toxicological data and curves[1] were obtained for 3,5-dinitro-*o*-cresol and 2,4-dinitrophenol in studies with eggs of *L. kalmii*.

[1] The data and curves are taken from an unpublished report of March 22, 1935, by J. F. Kagy. The manuscript is on file with the Crop Protection Institute, Durham, New Hampshire. The study was conducted at Iowa State College under the direction of C. H. Richardson. Cass F. Smith assisted in this phase of the investigation.

In table 4, data for the ovicidal experiments with petroleum-oil solutions of 3,5-dinitro-*o*-cresol and 2,4-dinitrophenol have been summarized. The data for the net mortalities, as given in table 4, were plotted against their respective concentrations in percentage of the nitrated phenol dissolved in the oil phase of the emulsions. The resultant curves are illustrated in figure 2, together with curve for 2,4-nitro-6-cyclohexylphenol, as published by Kagy & Richardson (1936). From these data and curves it is evident that petroleum-oil solutions of 2,4-dinitrophenol are much less toxic (about one-fourth) than either 2,4-dinitro-6-cyclohexylphenol or 3,5-dinitro-*o*-cresol. Statistical analysis of the data for 3,5-dinitro-*o*-cresol *vs.* 2,4-dinitro-6-cyclohexylphenol has not revealed a significant difference in toxicity to the insect eggs.

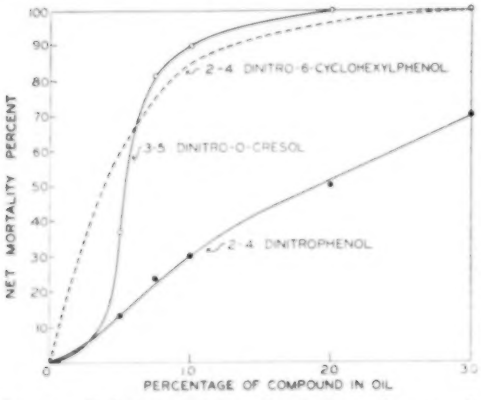



FIG. 2.—Relative toxicity of solutions of some nitrated phenols in petroleum oil to eggs of *Lygaeus kalmii* Stål.

**Table 4.—Relative toxicity of emulsified petroleum-oil[1] solutions of 2,4-dinitrophenol and 3,5-dinitro-*o*-cresol to eggs of *Lygaeus kalmii* Stål.**

| MATERIALS | PER CENT OF COMPOUND IN OIL | SAMPLE NUMBER EGGS | NET PER CENT MORTALITY[2] |
|---|---|---|---|
| Oil (2%) | — | 2900 | 0.0[3] |
| Oil plus 2,4-dinitrophenol (2%) | 0.50 | 400 | 13.7 |
| | 0.75 | 400 | 23.8 |
| | 1.00 | 400 | 30.8 |
| | 2.00 | 400 | 50.0 |
| | 3.00 | 400 | 70.0 |
| Oil plus 3,5-dinitro-*o*-cresol (2%) | 0.25 | 300 | 0.0[3] |
| | 0.50 | 300 | 36.7 |
| | 0.75 | 300 | 81.7 |
| | 1.00 | 400 | 90.0 |
| | 2.00 | 400 | 100.0 |
| | 3.00 | 400 | 100.0 |

[1] A dormant type of petroleum oil having the following specifications: specific gravity (20°C), 0.8815; unsulfonatable residue, 82 per cent; viscosity (Saybolt 100°F), 99–100 seconds; boiling range, 606° to 742° F.
[2] Includes embryos and newly hatched nymphs.
[3] The percentage mortality was 40 per cent.

The results of toxicity experiments with oil solutions of 3,5-dinitro-*o*-cresol applied as emulsions to San Jose scale are summarized in table 5. The net mortalities of the compound and of petroleum oil were plotted against their respective concentrations in percentage of the phenol dissolved in the oil phase of the emulsion. The curve is illustrated in figure 3, and a curve for 2,4-dinitro-6-cyclohexylphenol, published by Kagy & Richardson (1936), has been included. The curves show that the oil solutions of 3,5-dinitro-*o*-cresol are less toxic to San Jose scale than the oil solutions of 2,4-dinitro-6-cyclohexylphenol. The difference in toxicity is undoubtedly significant.

**Table 5.—Relative toxicity of emulsified petroleum-oil[1] solutions of 3,5-dinitro-*o*-cresol to the San Jose scale, *Aspidiotus perniciosus* Comstock.**

| MATERIALS | PER CENT OF COMPOUND IN OIL | PER CENT MORTALITY[2] | NET PER CENT MORTALITY[2] |
|---|---|---|---|
| No treatment | — | 26.0 | |
| Oil (1.0%) | — | 58.0 | 0.0 |
| Oil plus 3,5-dinitro-*o*-cresol (1.0%) | 0.25 | 60.3 | 5.5 |
| | 0.50 | 69.7 | 27.8 |
| | 1.00 | 82.0 | 57.1 |
| | 2.00 | 94.0 | 85.7 |
| | 3.00 | 99.3 | 98.4 |

[1] A dormant type of petroleum oil. (For specifications see footnote[a] of table 5.)
[2] Each mortality value was determined from a sample of 600 scale insects.

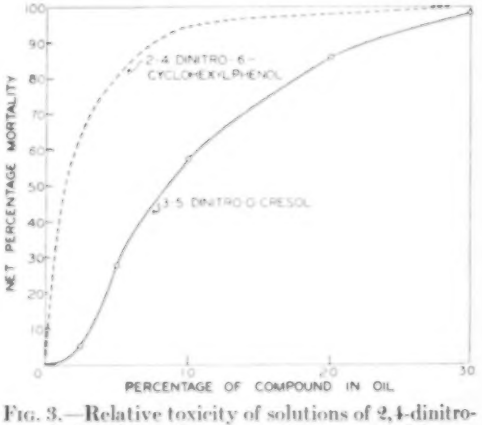



FIG. 3.—Relative toxicity of solutions of 2,4-dinitro-6-cyclo-hexylphenol and 3,5-dinitro-*o*-cresol in petroleum oil to the San Jose scale.

The toxicities of 2,4-dinitro-6-cyclohexylphenol, 3,5-dinitro-*o*-cresol and 2,4-dinitrophenol in petroleum-oil solutions have been compared in limited and somewhat inconclusive studies with several other species of insects including immature larvae of the codling moth, *Carpocapsa pomonella* L. and of the adult bean aphid, *Aphis rumicis*. The oil solutions of 2,4-dinitro-6-cyclohexylphenol were unquestionably more toxic than oil solutions of the other phenols.

Certain mixtures of petroleum oil with the nitrated phenols 2,4-dinitro-6-cyclohexylphenol, 3,5-dinitro-*o*-cresol, and 2,4-dinitrophenol[1] have been tested rather extensively by many workers in the field and on many species of insects that are possible to control with dormant sprays. The proprietary mixtures employed have not been comparable; consequently, little can be concluded concerning an exact picture of the relative effectiveness of these nitrated phenols in oil solutions applied under field conditions. When employed in certain mixtures and under certain conditions, both 2,4-dinitro-6-cyclohexylphenol and 3,5-dinitro-*o*-cresol in petroleum-oil combinations have proved effective as dormant sprays.

NITRATED PHENOLS IN DUST MIXTURES.—Boyce *et al.* (1939b) reported that 2,4-dinitro-6-cyclohexylphenol, when dispersed on certain inert diluents at the rate of 1.0 per cent, was very effective as a dust for the control of several species of mites on citrus and Persian walnuts. A detailed account of the methods of preparation, toxicity, effectiveness, and utility of this dust, known commercially as *DN-Dust*,[2] was disclosed. It was found that the lethal deposit of the chemical applied in a 1 per cent dust mixture with walnut-shell flour to the citrus red mite, *Paratetranychus citri* (McG.), was about 0.4 microgram per square centimeter. By means of the same toxicological procedures, lethal deposits of several closely related nitrated phenols have been determined for the mite.

The most vigorous adult female mites were selected from fruit collected from scattered field infestations. These mites were systematically transferred to the surfaces of the dusted fruits of each treatment. Mortality determinations were made at intervals of 24 hours, over a period of 72 hours.

Because of the wide variation in the vitality and susceptibility of mite populations in the field, and because of the failure to rear successive generations of uniformly reactive mites under laboratory conditions, it was imperative that the toxicity experiments be so designed that each of the comparisons of the effect of the chemicals be made on the same mite populations. The effects of the phenols on the mites were not influenced materially by population variance, because of the multiple-pairing type of design.

**Table 6.—Approximate deposits of some nitrated phenols in walnut-shell flour dust mixtures lethal to the adult female citrus red mite, *Paratetranychus citri* (McG.).**

| COMPOUND | LETHAL DEPOSIT OF COMPOUND, IN MICROGRAMS PER SQUARE CENTIMETER |
|---|---|
| 2,4-Dinitro-6-cyclohexylphenol | 0.40 |
| 2,4-Dinitro-6-ethylphenol | 1.20 |
| 3,5-Dinitro-*o*-cresol (2,4-dinitro-6-methylphenol) | 1.80 |
| 2,4-Dinitrophenol | 3.10 |
| Dinitro-α-naphthol | >3.40 |

The deposits of the chemicals per unit area of fruit surface were determined by colorimetric analyses in which standard solutions of the sodium salts of the phenols were employed. The approximate values of the lethal deposits, that is, the amount of chemical per unit area necessary for perfect control, were estimated from net mortality-concentration curves. For each curve, approximately 6,000 mites were used. The differences in toxicity of the nitrated phenols were sufficiently large, and the ranges of the data were scattered so separately that statistical treatment of the existent mean differences was not essential. With the less toxic nitrated phenols, it was necessary to prepare 2 and 3 per cent dusts in order to deposit a sufficient quantity of the chemical per unit area of fruit surface to give a measurable mortality of mites. The approximate values for the lethal deposits are shown in table 6.

It is evident from these data that 2,4-dinitro-6-cyclohexylphenol is approxi-

[1] United States Patents Nos. 2,121,038 and 2,121,039.
[2] Manufactured by The Dow Chemical Company, Seal Beach, California.

mately three times more toxic than 2,4-dinitro-6-ethylphenol, about four times more toxic than 3,5-dinitro-*o*-cresol and about eight times more toxic than 2,4-dinitrophenol. Dinitro-α-naphthol was not measurably toxic to the citrus red mite.

The laboratory method is a rather severe test, because the mites are not dusted directly. Dust mixtures of these nitrated phenols were therefore applied in the field for the control of the citrus red mite. It was found that the field results compared favorably with the laboratory findings. The phenols other than 2,4-dinitro-6-cyclohexylphenol showed very little promise in the control of the mite. Dinitro-*o*-cresol was of special interest because its potential use had been frequently suggested. Dust mixtures containing 2 per cent of the cresol were tested repeatedly in field plots adjacent to blocks treated with dusts containing 1 per cent 2,4-dinitro-6-cyclohexylphenol. The initial mortality of mites and the residual effectiveness of 3,5-dinitro-*o*-cresol was inferior to 2,4-dinitro-6-cyclohexylphenol. Dinitro-*o*-cresol has a lower melting point (86° C.), and the crystals of the phenol sublime more rapidly than 2,4-dinitro-6-cyclohexylphenol (M.P. 106° C.). Where two timed applications of *DN-Dust* are necessary for lasting mite control, it was found that under the best conditions at least three applications of a 2 per cent 3,5-dinitro-*o*-cresol dust would be required. In situations where the mite populations are on the downward trend of the population curve, some good results have been obtained with 3,5-dinitro-*o*-cresol; where the mite population curve is on the upward trend, erratic and generally unsatisfactory results followed.

DISCUSSION.—Owing to the large number of insect species of economic importance, it is difficult to draw broad conclusions regarding the toxicity of any group of organic compounds. Specificity and wide variations in toxicity are to be expected, since the morphology and physiology among the systematic groups are so heterogeneous. Even among species of a genus, reports of wide variations in susceptibility to poisons have been noted in the literature.

One characteristic of 2,4-dinitro-6-cyclohexylphenol is very outstanding: This compound, with many of its inorganic and organic salts in many compositions, has been tested on numerous species of insects and mites, and no marked specificity in toxicity to insects, such as has been reported of certain toxicants as, for example, phenothiazine and rotenone, has ever been noted. The lack of toxicity of the chemical in dust mixtures to adult aphids might be referred to as an exception. Aqueous and petroleum-oil solutions are toxic to aphids, however. The phenol is toxic as a contact and stomach poison and in the gaseous state. It is of academic interest only to note that the vapors of the phenol have shown limited toxicity to the confused flour beetle, *Tribolium confusum* Duval, and to crawlers of the California red scale, *Aonidiella aurantii* (Mask.). The nitrated phenol is of economic importance as a contact poison in dormant sprays for the control of many species of insects and in dust mixtures for the control of mites and thrips. So far, no use for the compound or one of its salts as a stomach poison has been developed. There are many promising indications, however, which point to the possible development of certain less phytotoxic salts as stomach poisons.

Of recent interest is the dicyclohexylamine salt of 2,4-dinitro-6-cyclohexylphenol. Like the other salts of the phenol, the dicyclohexylamine salt is very toxic as a stomach poison. At present, this salt is of economic importance in certain dust compositions (Kagy & McCall 1941; Boyce & Kagy 1941) which have value in the control of mites and several species of thrips on a large number of agricultural crops.

Other 2,4-dinitro-6-R-phenols have been studied in a manner similar to that used in the study of 2,4-dinitro-6-cyclohexylphenol, but to a much more limited extent. Many of the most toxic compounds, such as 2,4-dinitro-6-*n*-hexylphenol and 2,4-dinitro-6-*n*-heptylphenol, have been of academic interest; and the lower series members, such as 2,4-dinitrophenol and 3,5-dinitro-*o*-cresol, have not proved adequately toxic in many instances.

Since it was first used as an insecticide, in 1892, 3,5-dinitro-*o*-cresol has had limited commercial use for the control of insects on dormant trees in Europe and for the control of grasshoppers in Africa and in certain South American countries. In this country, until 1936, the chemical had been tested and generally discarded

by many entomologists, as reported in published and unpublished work. The development of petroleum-oil solutions of 2,4-dinitro-6-cyclohexylphenol for dormant sprays has stimulated new interest in 3,5-dinitro-*o*-cresol, and certain insecticidal compositions have been employed to a greater extent commercially in the last several years.

The first member of the series of 2,4-dinitro-6-R-phenols is, essentially, 3,5-dinitro-*o*-cresol (2,4-dinitro-6-methylphenol). The initial members of such series are expected to behave peculiarly in their toxic properties as well as in their physical and chemical properties, and the toxicity of this nitrated cresol, among diversified groups of insects and mites, has been accordingly erratic and generally unpredictable. In certain instances, as, for example, in the ovicidal studies with eggs of *Lygaeus kalmii*, the toxicity of the compound was at least equal to the toxicity of 2,4-dinitro-6-cyclohexylphenol. In the other studies with the compounds as toxicants in oil, as stomach poisons, and as acaricides in dust mixtures, 3,5-dinitro-*o*-cresol was definitely less toxic than 2,4-dinitro-6-cyclohexylphenol, and in the normal order expected in relation to the toxicity of other members of the series.

Among heterogeneous groups and classes of organic compounds no general relation of structure to insect toxicity has been determined. In the literature, however, many relationships of structure to toxicity among homologues, analogues, position and stereo-isomers have been pointed out. There appear to be some definite toxicological relationships of structure among members of this group of 2,4-dinitro-6-R-phenols.

PHYTOCIDAL ACTION OF THE COMPOUNDS.—Published information concerning the relative phytocidal action of members of this group of compounds is almost entirely lacking. Proprietary mixtures containing certain of these chemicals are quite different, and there is, as a consequence, much conflicting information. There appear to be some interesting incidences of specificity of action on certain families and genera of plants. When properly compounded in insecticidal mixtures, these chemicals and their salts can be employed with safety on most plants, at the same time controlling certain insects and mites. The field of investigation is essentially virgin, and with the continued use of these chemicals in economic entomology, much valuable information will be forthcoming.

RELATIVE TOXICITY TO MAN.—2,4-Dinitrophenol is well known to medical science because of its use as a potent metabolic stimulant. Tainter & Cutting (1933) studied the chronic toxicity of 2,4-dinitrophenol and ascribed cataract formation to the repeated ingestion of the drug. Tainter *et al.* (1935) pointed out that its use might cause undesirable side actions, such as skin rashes, peripheral neuritis, and agranulocytosis. Dodds *et al.* (1933, 1934) suggested the use of 3,5-dinitro-*o*-cresol because they found the drug to be about five times more active in man than 2,4-dinitrophenol.

Heymans & Casier (1935) studied the pharmacological action of 2,4-dinitrophenol, 3,5-dinitro-*o*-cresol, 2,4-dinitro-6-cyclopentylphenol, and 2,4-dinitro-6-cyclohexylphenol on pigeons. Tainter *et al.* (1935), using different methods, studied the action of the drugs in pigeons, rats, and dogs. The limited number of tests with the compounds administered to laboratory animals were either contradictory or indicated insignificant differences. Tainter *et al.* pointed out that the toxic side actions with humans could not be ascertained with tests on laboratory animals. They agreed with Heymans & Casier (1935) that the cyclic derivatives would not stimulate human metabolism.

Pastac (1937) reviewed the clinical evidence and pharmacological background of 2,4-dinitrophenol and 3,5-dinitro-*o*-cresol and noted that many accidental deaths have been caused by 2,4-dinitrophenol and 3,5-dinitro-*o*-cresol. Because of the increasing significance of 2,4-dinitro-6-cyclohexylphenol as an insecticide, Hrenoff & Leake (1939) reported on the toxicity of the compound to three species of mammals and concluded that there was no public health hazard. For workmen handling the chemical, they suggested certain precautions based upon general information of the pharmacology and toxicology of the nitrated phenols.

Boyce *et al.* (1939a) reviewed the pharmacological background of 2,4-dinitro-6-cyclohexylphenol and stressed the fact that the compound was toxic only in comparatively large doses and that in records of many individuals working with the

chemical over periods of several years, no toxic symptoms attributed to 2,4-dinitrophenol and 3,5-dinitro-*o*-cresol had been reported.

It appears, therefore, that 2,4-dinitro-6-cyclohexylphenol and 2,4-dinitro-6-cyclopentylphenol are worthless as metabolic stimulants in man. It is of interest to note that the apparent order of toxicity of the 2,4-dinitro-6-R-phenols to humans is possibly in the reverse order of that to insects and mites. This relationship of toxicity has been responsible, in part, for the commercial development of 2,4-dinitro-6-cyclohexylphenol as an insecticide.

SUMMARY.—An investigation concerned with the relative toxicity to several species of insects and mites of some 2,4-dinitro-6-R-phenols in which R represents a hydrogen or certain alkyl or alicyclic groups is reported.

The chemistry of the 2,4-dinitro-6-R-phenols is very similar, but the physical properties vary considerably. From a résumé of the literature and from the additional data presented, it can be rather definitely concluded that 2,4-dinitrophenol is considerably less toxic to insects and mites than 3,5-dinitro-*o*-cresol (2,4-dinitro-6-methylphenol).

In the study of the compounds as stomach poisons, some relations of structure to toxicity are pointed out. An increase in the length of the normal alkyl chain up to 6 or 7 carbon atoms resulted in a progressive increase in toxicity of the compounds to the silkworm, *Bombyx mori* L. The 2,4-dinitro-6-*n*-octylphenol was less toxic than either 2,4-dinitro-6-*n*-heptylphenol or 2,4-dinitro-6-*n*-hexylphenol. This evidence indicated a further decrease in toxicity with an increase in length of the alkyl chain beyond 8 carbon atoms. The *n*-hexyl and the *n*-heptyl derivatives, which were the most toxic compounds tested, were about twelve times more toxic than 3,5-dinitro-*o*-cresol, which is the initial member of the series. The 2,4-dinitro-6-cycloalkylphenols were less toxic than their respective analogues, although the difference was not numerically large. The 2,4-dinitro-6-cyclohexylphenol was about seven times more toxic to the silkworm than 3,5-dinitro-*o*-cresol. All the 2,4-dinitro-6-R-phenols were more toxic to the silkworm than acid lead arsenate, but were less toxic than rotenone. The 2,4-dinitro-6-cyclohexylphenol was more toxic than 2,4-dinitro-6-cyclopentylphenol to larvae of *Cynthia cardui* (L.) and to larvae of the Colorado potato beetle, *Leptinotarsa decemlineata* (Say).

Petroleum-oil solutions of 2,4-dinitro-6-cyclohexylphenol were more toxic than petroleum-oil solutions of 3,5-dinitro-*o*-cresol to the San Jose scale, *Aspidiotus perniciosus* Comstock, to the bean aphid, *Aphis rumicis* L., and to newly hatched larvae of the codling moth, *Carpocapsa pomonella* L. The petroleum-oil solutions of the two compounds were not significantly different, however, in their toxicity to eggs of *Lygaeus kalmii* Stål. Petroleum-oil solutions of 2,4-dinitrophenol were much less toxic to eggs of *L. kalmii* than the solutions of 3,5-dinitro-*o*-cresol or 2,4-dinitro-6-cyclohexylphenol.

An investigation concerned with the toxicity of some 2,4-dinitro-6-R-phenols in dust mixtures for the control of the citrus red mite, *Paratetranychus citri* (McG.), is also reported. It was found by the determination of lethal deposits on fruit surfaces that 2,4-dinitro-6-cyclohexylphenol was about three times more toxic than 2,4-dinitro-6-ethylphenol, about four times more toxic than 3,5-dinitro-*o*-cresol, and about eight times more toxic than 2,4-dinitrophenol. Dinitro-$\alpha$-naphthol was not measurably toxic to the citrus red mite. These laboratory results were confirmed by field studies.

The lack of marked specificity of toxic action of 2,4-dinitro-6-cyclohexylphenol to insects is discussed. Because 3,5-dinitro-*o*-cresol is, essentially, the first member of the series of 2,4-dinitro-6-R-phenols, the chemical can be expected to behave peculiarly in its toxic properties among diversified groups of insects and mites.

Certain literature relative to the pharmacology and toxicology of the 2,4-dinitro-6-R-phenols is reviewed. From present information it appears that the order of toxicity of the compounds to humans is possibly in the reverse order of that of these compounds to insects and mites.[1]

[1] ACKNOWLEDGMENTS.—This investigative work, which was conducted at Iowa State College, Ames, Iowa, and at the University of California Citrus Experiment Station, Riverside, California, has been made possible by generous cooperation and grants from The Dow Chemical Company, Midland, Michigan. The writer wishes to express his appreciation to these organizations; to Dr. C. H. Richardson, of Iowa State College, for his many helpful suggestions and for review and criticism of the manuscript; and to Dr. A. M. Boyce, of the University of California Citrus Experiment Station, who cooperated in the studies on the citrus red mite. It is also a pleasure to acknowledge the very able assistance rendered by G. L. McCall, formerly of the University of California Citrus Experiment Station.

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## MEXICAN BEAN BEETLE IN SOUTH DAKOTA

The Mexican bean beetle, *Epilachna varivestis* Mulsant, has been found doing a limited amount of damage to garden beans in Spearfish, South Dakota. This is the first known record of this insect in this state.

The beetles and their larvae were found in August doing damage to about fifteen bean plants in one end of a small bean patch located in the north east edge of Spearfish. County agent Ivan V. Fluharty was unable to locate any other infestations in the vicinity. Control measures were immediately applied in the field infested and a warning given in the vicinity.

Spearfish, in Lawrence county, is on the northern edge of the Black Hills about eight miles east of Wyoming and approximately midway between Nebraska and North Dakota, and is the location of a number of small farms where vegetables and small fruits are intensively grown.—10-2-41.

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# Application of Commodity Treatments for the Alleviation of Quarantines

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Commodity treatments for the alleviation of quarantines, like a number of other branches of economic entomology, seeks, by the use of formulae and technique of application, to effect the destruction of some form of insect life. They differ from the ordinary pest control efforts only in the degree of thoroughness required for their successful application, since the objective is complete disinfestation of the commodity in order that no hazard of pest distribution may attach to its movement.

As a prelude to a discussion of early day efforts in commodity treatments, a brief sketch of the conditions which occasioned these efforts may help in promoting a better understanding of the problem.

The latter half of the nineteenth century witnessed a vast colonizing movement. With it came an increasing exchange of plants and plant products. Both individuals and governments engaged in the introduction of new plants from foreign lands in order that the number and value of their crops might be increased.

California, by reason of its geographical position and its mild climate, became the proving ground for many new kinds of plants, particularly oriental origin.

Too late it was found that some of these new introductions supported forms of insect life that had become domiciled on them in their native land, and that a number of these species, relieved of natural checks in their new environment, had, figuratively speaking, bred and mustered.

The impact of these new species on a new and promising horticultural industry not only caused grave concern to fruit growers but acted as a powerful stimulant to the science of economic entomology. Early workers in this field recognized not only the urgent need for insecticidal formulae to combat them, but also measures to prevent their spread. Both entomologists and forward looking growers became convinced of the necessity for securing proper legislation.

Unfortunately, though legislation was secured, much opposition was encountered to the regulations laid down for the disinfestation of commodities and the horticultural officials who attempted to enforce them were taken into court and the law declared unconstitutional.

Those commodities most in need of disinfestation consisted of nursery stock and fruit, particularly the former. Insecticidal formulae available for such work was limited to hydrocyanic acid, carbon bisulphide and certain sprays of doubtful value. The properties of fumigants were not thoroughly understood. This lack of knowledge was reflected in the manner of their application. For example, no consideration was given to the effects of the commodity on the reactions of the fumigant. Questions of temperature, load factor, the presence of moisture, to say nothing of the proper fumigation equipment, pre or post treatment care as we know it, were simply not considered. Their application was left to those most interested. No staff of trained entomologists was on hand to instruct them in proper procedure.

In view of the influence which these attempts at early treatment have had on the subsequent attitude towards treatments, it is interesting to examine the causes which led to their failure. Broadly speaking, these can be generalized under two heads—the first is limited formulae and technique, and the second is lack of proper organization to administer them.

New insect introductions had by this time increased to such numbers as to constitute a real menace and some, the grape phylloxera, San Jose scale, and other coccids, had already started their eastward march. The Colorado potato beetle, though a native species, had forsaken its original host, the buffalo bur, and started eastward, being checked only by the Atlantic Ocean. The gypsy moth appeared only in the New England States. The boll weevil had crossed the Mexican border. Both the Mexican fruit fly and the Mediterranean fruit flies were objects of grave concern due to the receipt of infested fruit arriving at California ports.

As a result of this failure, the idea be-

came firmly implanted that the only way to prevent the advance of these undesirables was to prevent the movement of all carriers and hosts. In this manner the plant quarantine idea came into being. In their early application quarantines were purely state matters. The Federal Government had not yet concerned itself with plant quarantines. In California, county quarantines prevailed. Under this system a veritable maze of state and even county quarantines were promulgated, each seeking to prevent the introduction or spread of some particular pest.

The promulgation of a plant quarantine law by Congress relieved the pressure on the states, as the Federal Government took over a number of them, which contributed to uniformity.

Among foreign insects most feared and against which embargo types of quarantines had been erected was the pink bollworm of cotton, a native of India. It had spread to Egypt where it became a pest of major importance. It later appeared in Mexico, where it reduced the cotton crop from 15 to 50 per cent in districts where it became established. With the importation of Mexican cotton, the hazard of its introduction into the continental United States was not beyond conjecture. It also posed a new question in the administration of plant quarantines. The cotton spinning industry of the United States was of such magnitude that an embargo quarantine on cotton must necessarily produce serious repercussions and was, in fact, out of the question.

At this time, two investigators of the United States Department of Agriculture —L. A. Hawkins and E. R. Sasscer—were engaged in improving methods of treating seeds by utilizing a preliminary vacuum for the purpose of securing better penetration. Their work had already, under limited conditions, demonstrated its efficiency in securing penetration of the fumigant far beyond that achieved by atmospheric fumigation and suggested a solution to this very vexing problem.Preliminary tests confirmed the previous belief and vacuum fumigation became an established procedure for treating cotton. Its extension to industrial practice became only a problem of mechanics. Thus, commodity treatments became reinstated.

Though probably little thought was given to it at the time, the industrial application of vacuum fumigation to the treatment of baled cotton to destroy pink boll worm involved practically all of the factors necessary for success of a commodity treatment to alleviate a quarantine. They are:

(1). A great and immediate need backed by a powerful organization.

(2). A treatment requiring capital investment of sufficient amount to cause its centralization at specified points.

(3). Operation and upkeep of equipment, requiring mechanical and engineering ability to assure their proper operation.

(4). Equipment permitting installation of such accessories as recording gauges, thermographs, etc., reducing the effects of human element to a minimum.

(5). The product to be treated—delivered only at specified points.

The far-reaching effects attending the treatment of cotton had much to do with bringing about a change of perspective in regard to commodity treatments. Only a few years following the advent of vacuum fumigation, the source of origin of corn borer infestation was found to be in imported baled broom corn. While formulae completely lethal to pink bollworm were found to be unsuccessful in destroying the corn borer larvae in broom corn, it did not take long for specialists of the United States Bureau of Entomology and Plant Quarantine to determine that it would readily succumb to heat and that by a system of evacuating the air and injecting aquous vapor in the form of high pressure dry steam, all borer populations in the bales were destroyed. Again with the advent of the Mediterranean fruit fly in Florida, the implications of an embargo type of quarantine were so great that experimental data on thermal treatment developed previously in Mexico in connection with the Mexican fruit fly were overhauled and the utilization of hot vapor treatment inaugurated on a commercial scale. In this treatment the fruit was exposed to saturated water vapor at 110° F. for ten hours. A second thermal treatment involves the exposing of fruit to subatmospheric temperatures of 32° and 31° F. and exposure at these low temperatures for a week or more. Both of these forms have since become approved and are used

in the alleviation of plant quarantines, involving three different species of fruit flies, the Mediterranean, Mexican and melon flies.

The discovery of the insecticidal value of methyl bromide opened the way for a new and direct approach to the application of commodity treatments to nursery stock, fruits and vegetables in connection with the Japanese beetle, the oriental fruit moth and the white-fringed beetle. Its use is also authorized in connection with the treatments applied to fruit and vegetables to destroy both the Mediterranean and melon fruit flies, and numerous other insect species regulated by state quarantines. There is perhaps a greater diversity of products treated with this compound than any other approved for commodity treatments.

The major commercial application of commodity treatments of products otherwise under quarantine falls into two categories: (1) thermal treatments involving hot water, hot vapor and chilling process, and (2) gaseous insecticides. While there may be other methods in use, the great bulk of all treatments for the alleviation of plant quarantines fall into one or the other of these groups.

A study of these methods approved at the present time indicates that most all of them have one thing in common. The insect whose destruction is sought is subjected to completely lethal environment, in one case to a temperature in which it cannot long survive, and in the other, to a medium of toxic gas.

The effectiveness of these methods in alleviating quarantine restrictions has brought about an increasing desire on the part of both officials and individuals, such as nurserymen, produce dealers, and fruit packers and growers, to avail themselves of the benefits to be derived from extending their business to markets otherwise closed by quarantines. It has led to an urgent demand for extension of commodity treatments in an attempt to destroy new pests.

In any consideration of this subject, the fact must not be lost sight of that the situation today contains many of the same elements of the problems of early day workers. For example, the number of workers in this field are few, confined largely to the Federal Bureau of Entomology and Plant Quarantine and the State of California. Each has its own problems. In the one case the problems concern pests of both international and interstate movement, while the other deals more largely with the interstate and intrastate movement of regulated products with which the Federal Government has not concerned itself, and with purely local problems.

Though great progress has been made in both the international and interstate fields, the problems in both fields involve serious consideration of the possible limits of their extension. During the current year, a tonnage of fruit and vegetables moved under commodity treatments as a condition of movement that could not be estimated under seven figures. These include citrus fruit treatments with hot and cold treatments to destroy Mexican fruit flies of the genus *Anastrepha*, fumigation of fruit and vegetables, including green corn, potatoes, onions, beets, carrots, melons, etc., with methyl bromide to destroy Japanese beetle. The same fumigant is used to treat the winter crop of green beans from Cuba, prior to importation into the United States, to destroy the Indian pod borer (*Maruca testulalis*). A large amount of nursery stock moves under atmospheric fumigation, which removes the hazard of its carrying Japanese beetle, oriental fruit moth and white-fringed beetle. Hydrocyanic acid is employed in the disinfestation of a vast tonnage of cotton from all parts of the world and from infested areas within the United States to destroy pink bollworm. A long series of lesser commodities requiring treatments are treated with one of a number of various gaseous insecticides and hot vapor, including carbon disulphide, chloropicrin, hydrocyanic acid and methyl bromide, the selection of which is elective, for destruction of the vetch weevil, the strawberry mite and other related species. In this connection, the Regional Plant Boards play an important part. The solution of these problems affords a basis for a better understanding of the action of fumigants.

The properties of gases are reflected in the reaction between the commodity and the fumigant and vice versa. Among the most important reactions of fumigants is that phenomenon designated as adsorption. "All solids tend to adsorb or condense upon their surfaces any gases or

vapors with which they come in contact. The amount of adsorption for given conditions of temperature and pressure varies with the nature and physical state of the solid and of the nature of the gas. In other words, adsorption is specific and selective. With the same gas and the same solid the amount of adsorption is greater the higher the pressure, the lower the temperature."[1] The influence of adsorption seems to be little understood, yet is perhaps a major factor, influencing the success or failure of fumigation methods. In the application of commodity treatments it is influenced by such things as the load factor, that is, the relationship of the load to space in the fumigator. It still seems to be a general belief among those who are not familiar with the problem that the dosage should be altered in direct relationship to the load, with the dosage schedules being cut to make up for load displacement. Such a course ignores the question of the increased surface area available for adsorption.

Study in the effects of commodity treatments already indicates that during fumigation a progressive reduction in the concentration of such gases as hydrocyanic acid is indirect to the amount of the load, i.e., the surface coming in contact with the gas. For example, an analysis of HCN concentration in a 300 foot fumigator containing a load of 100 balled citrus trees under standard vacuum fumigation procedure shows a 14 per cent higher concentration of HCN in cases where the foliage of trees has been removed than in cases where it has been allowed to remain. A fumigator can be loaded to a point which will nullify the lethal value of the fumigant. These same analyses indicate that adsorption continues to a point where the ability of the commodity to attract the vapors of the fumigant and the tendency of the vapors to mingle with the gases of the atmosphere meet. The effects of pressure on the reaction of the fumigant cannot be overlooked. For example, the exposure at sub-atmospheric pressure tends to reduce adsorption, and permits more rapid diffusion of the fumigant between the interstices of the product, increasing pressure, such as occurs when the vacuum is broken and pressure is permitted to rise, and causes increased adsorption and also increase in temperature.

[1] Bancroft's Applied Colloidal Chemistry, p. 3.

Great injury to living plants can come from stratification of gases in fumigating chambers. Those of high specific gravity, like carbon disulfide, have been noted to react in this manner. This factor should always be under control. A full load where a fumigant with a low adsorption coefficient is used can have the effect of greatly increasing the dosage as displacement will exceed adsorption. Experimental data tends to support the opinion that some gases at least are activated by increased temperatures, if we consider that more complete kill of insects with attendant injury to host plants often occurs. The converse seems to be true as regards the loss of efficiency of some fumigants at low temperatures.

In the case of methyl bromide, numerous tests indicate in the destruction of numerous species of scale insects that increased efficiency is notable between 79° and 85° F. Above 85° F. with the same kind of plants a considerably greater amount of injury occurs. Where temperatures are allowed to drop below 75° F., efficiency rapidly decreases, all other things being equal. In connection with the use of hydrocyanic acid gas, what is commonly known as protective stupefaction has been demonstrated.

The question of injurious residues in connection with the application of commodity treatments is often of considerable importance. Though it can be corrected sometimes by post-treatment handling, it is often overlooked. In the case of hydrocyanic acid, the difference between heavy fumigation injury and none at all often hinges on a simple expedient such as hosing off plants with water after treatment.

The fat solvent properties of methyl bromide are well known. In the presence of plant foliage containing oils, injury may be expected, sometimes to the extent that its value as an insecticide is destroyed.

In most cases of this nature, close observation will enable an avoidance of considerable injury.

The manner of pre- and post-treatment handling of plants under fumigation may often mean the difference between success and failure. In connection with the use of hydrocyanic acid employed in evacuo, exposure to direct rays of sunlight or winds immediately following completion of the treatment is very likely to cause serious injury.

Most plants have a definite period of growth and rest. The resting season in the temperate zone often is accompanied by a period of complete dormancy when the metabolism of the plant is at its lowest ebb. When in this condition, its tolerance to gases and insecticides is probably at its peak.

Of all factors affecting the general efficiency of commodity treatments of living plants, variance in their tolerances to the different gaseous insecticides is the most difficult to forecast or to overcome. It is often the case that a single insect species has a host index of one hundred or more species. In general, it may be said that the problem of successful fumigation of any insect may be multiplied by its host index as each sometimes will be found to present a separate problem. The problem may vary according to the plant's structure, growth habits, its physical make-up or, in fact, any deviation from the host type.

Extensive application of treatments to alleviate the restrictions of plant quarantines indicates that tolerance of plants follow no fixed line. We are prone to group availability of a treatment according to species, genera or even family. Such assumption is not warranted.

Many varieties of hybrid azaleas are resistant to the vapors of methyl bromide, yet a few varieties, such as Coral bell, Salmon Pink and Twenty Grand, are entirely intolerant.

In the treatment of orchids a wide range of tolerance and intolerance to fumigants presents a difficult problem.

Cattleyas, Lycastias, Oncidiums and a number of other species tolerate the vapors of methyl bromide to a considerable extent, while Cymbidiums, Vandas and Dendrobiums are less tolerant, yet manifest considerable tolerances to the vapors of hydrocyanic acid.

Though Cypripediums in general are very intolerant to the former compound, some plants suffer no ill effects, indicating considerable variation of individual plant tolerance.

It seems to be a well established fact that insects in certain stages of development succumb to fumigation dosages that in other stages are sub-lethal in their effects, just as there is a difference in the resistance of different insect orders to the same fumigant. Camellia scale, *Parlatoria camelliae* is a common pest of the camellia plant, infesting both sides of the leaf. In the adult stage it is readily killed by atmospheric fumigation with methyl bromide at two pounds per 1,000 cu. ft. The plant is entirely tolerant to a dosage sufficient to destroy the scale. Fumigation delayed until spring, to be effective must be lethal to the eggs, young and adults, and requires a higher dosage. The condition of the plant at this time is most unfavorable as a new flush growth is present and injury may be expected. In the case of the juniper scale, *Carulaspis visci* Ferris = *Diaspis carueli* Comstock, the opposite seems to be the case. The viability of the eggs of this scale is destroyed at dosages which fail to kill the adult. This spring treatment of hosts of this coccid reduces the problem of the scale destruction, though the factor of plant tolerance increases. The oyster shell scale, *Lepidosaphes ulmi*, common on some nursery stocks, spends the winter in the egg stage, which at this time is highly resistant to the vapors of the above compound, yet it is readily killed in other stages.

While the tolerance of a plant may profoundly influence the value of a treatment, a compensating treatment may be given. For example, it is some times found that a light dosage for longer periods will suffice where a heavier dosage for a shorter period might prove injurious or vice versa. In a number of species of plants the lethal curve and the tolerance curve closely approximate and parallel each other. It is in these cases that optimum conditions for treatment have their application. Ability to control conditions of treatment, including temperatures, humidity, and selection of the period of greatest plant tolerance, may enable successful treatment of plants where permanent injury might otherwise result.

The question of what constitutes proper pre-conditioning of a commodity for treatment may imply a controlling of a number of factors that influence the efficiency of the treatment and would include both the host plant (perhaps for reasons of tolerance) and the insect pest, to bring it out of dormancy and for the purpose of its effect on the reaction between the fumigant and the commodity. It may contemplate such consideration as operating

temperature, pre-treatment heating, preliminary wetting, humidifying or prior drying off.

Pre-treatment conditioning is necessary for the successful fumigation with methyl bromide of citrus nursery stock infested with red scale, particularly in cool weather. To obtain a consistent kill using 2 pounds per thousand cubic feet for two hours, it was necessary to expose the scale and trees to a temperature of 80° to 85° F. for a sufficient period of time to permit all parts of the host supporting the scale to reach this temperature. Exposure of red scale to the vapors of this fumigant under such conditions has in all cases observed been completely lethal to this coccid. Counts of insects have exceeded 50,000. Exposure for the same period at the same temperature without preheating will result in kill largely according to location. The greatest survival will appear on the older and heavier wood which is slow to heat up and which largely influences the temperature of this scale.

An unlooked for development in the application of commodity treatments is a growing tendency to utilize them as a means of escaping the responsibilities of grading. Already two states have passed quarantine regulations against California potatoes, making fumigation a condition of movement, and both affirm that the only reason for such action is that their states otherwise become the dumping ground for wormy potatoes.

A second example of how a commodity treatment to alleviate a quarantine can be contravened is at this time in process of development. Certain states have placed quarantines on California potatoes on account of tuber moth. Their quarantines stipulate a certain treatment, the same to be certified to by an official of the state of origin, who must also attest to protection from post-treatment infestation and provide for continued identity of the shipment. Despite this type of regulation, untreated potatoes are moved out of California and are fumigated at railroad junction points in other states where, I am informed, a commercial fumigator does the fumigation, signs the certificate which is countersigned by the railroad agent, who is deputized by the state where the fumigation takes place, and who pays the cost of certification, which is added to the waybill. With the advent of winter the problem of fumigation will become increasingly more difficult, if not impossible. Obviously the original objective of the treatment has been sacrificed to a single consideration—convenience.

Newly awakened interest in the industrial application of commodity treatments to nursery stock brings with it a tendency towards decentralization. Experience of twenty years in the application of commodity treatments indicates that decentralization produces a situation where there develops a strong tendency to improvise. Though this decentralization may be due indirectly to lack of proper organization of the work, its consequences are the same. Where the responsibility of administering commodity treatments rests with a state or any governmental agency, officials should be in a position to supply information on design, construction of equipment, proper types of accessories, such as applicators, thermostats, humidifiers, heaters. etc. They should also be able to supply the latest information on such questions as dosage, pre- and post-treatment handling, tolerance of host, and pest resistance, and be backed by an organization that can enforce its mandates, such as standard types of equipment, according to industrial needs. Decentralization, if allowed to progress unregulated, may become a source of future trouble, involving not only injury to material treated, but also the scrapping of considerable investment in equipment. Worst of all, it will result in loss of faith.

Last, but not least, is the responsibility of those charged with the administration of commodity treatments to surround operations with proper safeguards for human welfare. All equipment and places of treatment should be properly signed if dangerous fumigants are in use. First aid kits, gas masks equipped with proper canisters should be at all times available, as should leak detectors where alkyl halide gases are used. Failure or negligence in this connection may result in serious injury or death.

The expansion of commodity treatments poses a vast number of new problems for investigators in this field which, if handled correctly, can go a long way towards furnishing relief from the restrictions of present plant quarantines. If allowed to get out of hand, they will do much to discredit and delay their popular acceptance.—7-23-41.

# Experiments with Several Wetting Agents in the Removal of Fluorine Spray Residue from Apples Sprayed with Natural Cryolite[1]

ERROL HAY KARR,[2,3] *Tacoma, Washington*

The use of certain wetting or degumming agents in dilute hydrochloric acid solutions for washing apples began with the work of McLean & Weber (1931), who found that this treatment aided in the removal of arsenical spray residues. They credited the improved results of the treatment to the addition of a wetting agent which resulted in a more effective contact between the acid solution and the spray particles.

Since the work of these investigators was published, certain wetting agents have found wide use in the removal of lead arsenate spray residues. The value of wetting agents in the removal of fluorine spray residues from fruit sprayed with natural cryolite, however, has not been very well established. Several patents have been granted to McLean & Weber (1935, 1937, 1938) covering the use of what they term wetting or degumming agents in dilute mineral acids for removing spray residues from fruit. A patent on the use of certain wetting agents in acid solution to aid in the cleaning of fruit has been granted to Carswell (1938).

Due to commercial reasons, most of the wetting or degumming agents on the market are identified by trade rather than chemical names. According to Roark (1937) there are three principle groups under which most of the commercial wetting agents can be classified: (1) the sulfated alcohols or alkyl sulfates, (2) alkyl sulfonates, (3) sulfonated products of such aromatic compounds as benzene, naphthalene and biphenyl. He has also called particular attention to the difference between sulfated and sulfonated compounds. The various compounds coming under the three groups are widely used in the textile industry as detergents and as wetting agents.

Observations have been made in the Yakima and Wenatchee districts in the state of Washington over a period of several years of results obtained in the commercial washing of apples. Although the addition of such trade wetting agents as *Vatsol* and *Hydralene* was often helpful in improving the removal of lead arsenate with hydrochloric acid solutions, it was indicated that the effectiveness in removing fluorine spray residue from natural cryolite sprayed fruit was not improved.

The majority of fruit washers used in these districts are of the double process, overhead-flood type, as illustrated by Robinson (1936). In this type of washer, sodium silicate or sodium carbonate solution is used in the first treatment for periods of 20 to 40 seconds, followed by a 1 to 1.5 per cent hydrochloric acid solution for periods of similar lengths. The temperatures of the solutions are generally maintained at 90° to 110° F. Only occasionally are wetting agents used in the flood-type machines, due to the fact that the amount that can be added is limited because of the excessive foaming that would occur in the highly agitated solutions. The use of defoaming compounds tends to counteract the beneficial effects of the wetting agents, and thus are of no particular value, Robinson (1936).

The use of the regular paddle flotation fruit washers is limited in the Yakima and Wenatchee districts for several reasons. Large quantities of fruit must be handled in a comparatively short time in the commercial packing plants and most fruit washed in this type of machine would have to be immersed in the solution for two minutes or longer, Overley *et al.* (1933). This length of time for exposure of fruit to the solution is an objectionable delay and also increases the possibility of fruit injury when using heated washing solutions. Because of the heavy spray programs used in the arid areas of the

[1] Publication of this paper has been secured by payment of the costs of printing.

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Pacific Northwest, the removal of spray residues at harvest is generally more difficult than experienced in other parts of the country, Haller (1935), and heated fruit washing solutions are generally required.

In the Yakima districts there is in use a number of fruit washers based on an improved flotation principle. With this machine the length of time that the fruit is exposed to the solutions is about the same as for the overhead-flood types in that it has means of raising the fruit above the solution and rapidly lowering it again at short intervals to facilitate the cleaning action. The operating principles are described in detail in a patent granted Morris & Cockrill (1936). The majority of these machines is used in tandem, as in the case of the overhead-flood types. Wetting agents are frequently added to both the acid and alkaline solutions to aid in the removal of lead arsenate spray residues.

After a study was made of notes on observations of commercial fruit washing and of the various literature pertaining to the use of certain wetting agents in the removal of fluorine spray residue, the following experiments were made. A special fruit washing machine was devised and the tests conducted under laboratory controlled conditions. Five different wetting agents were used in these particular tests which included soap bark and the four trade products, *Intramine-Y*, *Nekal BX*, *Vatsol*, and *Hydralene*.

DESCRIPTION OF FRUIT WASHER.—The special fruit washer used in the tests, it is believed, added to the flexibility and accuracy of the procedures employed.[1] The machine devised,[2] although different mechanically, duplicated the fruit washing action of the modified fruit washer developed by Morris & Cockrill (1936).

As in the commercial flotation machine, the cleaning action of the experimental fruit washer is dependent principally upon chemical rather than physical action in removing spray residues from fruit. Any change in the effectiveness, as the result of adding a wetting agent, would be more apparent under these conditions. By using the experimental fruit washer, it was possible to make more positive and accurate comparisons of different washing treatments without using large quantities of fruit.

The experimental fruit washer consists of three solution tanks mounted in a frame, together with a suitable mechanism for exposing the fruit to the cleaning action of the solutions used (Fig. 1). The top members of the frame support the operating mechanism, which is mounted

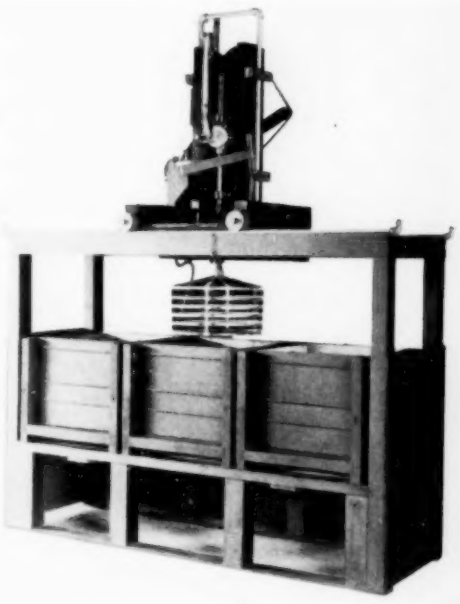

FIG. 1.—Front view of laboratory washer used in the experiment.

on a movable carriage. This carriage may be placed in the desired position over each tank and thus one mechanism may perform the duties of three independent stationary units. The operating mechanism consists of a monel metal fruit container firmly attached to the lower end of a vertical plunger shaft, which in turn is actuated by an electric motor operating through desired speed reduction units. The mechanism was so designed as to impart to the fruit container a vertical, reciprocal movement with a six-inch limit of travel, the rate of travel being variable through the use of a special drive. The result is a slowly ascending movement of the fruit container and a rapidly descending movement. In addition to the vertical,

[1] Karr, Errol Hay, 1937. Experimental fruit washer. Unpublished report, Tech. Dept., Penn. Salt Mfg. Co. of Wash.

[2] Acknowledgement is due Mr. Robert Karr for his helpful assistance in designing and constructing the experimental fruit washer.

reciprocal motion, the fruit container is given a partial rotation of about six inches during its travel, the direction of rotation being reversed as the direction of vertical travel is reversed.

In actual operation, the container rotates in a clockwise direction when in a submerged position, the reverse in direction of rotation taking place when the bottom of the fruit container is elevated above the tank solution. The level of the solution maintained was approximately one and one-half inches below the bottom of the container when at its highest point of travel. When the container was at its lowest limit of travel, fruit floating on the surface of the washing solution was not in contact with the bottom of the container, thereby permitting it to rotate in a clockwise direction without touching the fruit. The fruit was quickly released from its position on the bottom of the container upon its contact with the surface of the washing solution, when the rapidly descending movement of the plunger shaft occurred. In other words, the container bottom dropped rapidly away from contact with the fruit after the level of the solution was reached, thus permitting the falling fruit to submerge momentarily without encountering any obstruction. Then, on the ascending stroke, the container, moved slowly, lifting the fruit in a different position from that occupied on the descending stroke. The repetition of these movements caused the fruit to progress intermittently in a counter-clockwise direction.

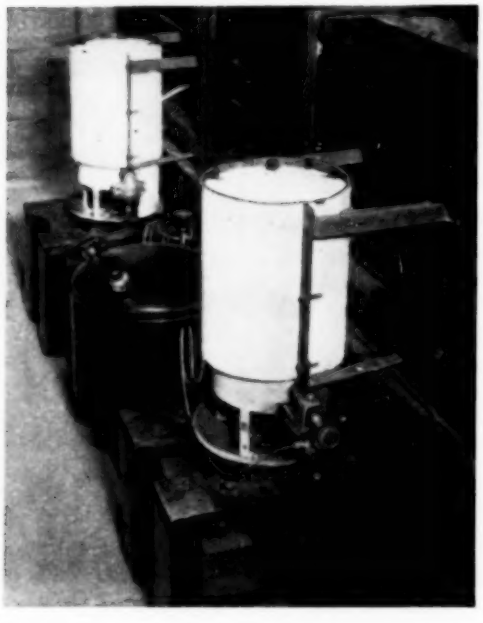

FIG. 2.—System for heating the solutions used in the experimental fruit washer. Acid resisting coils connected to the tanks are enclosed in insulated chambers over gasoline burners.

The operating mechanism is rigidly held over the center of any tank by a locking device on the carriage. Provision was made through a chain pull for a release of the locking device, as desired when moving mechanism from tank to tank. A hand lever permitted elevating the operating mechanism rapidly, which removed the fruit container from the tank solution after the desired exposure. This lever was so arranged as to remain in its extreme position until released.

An automatic interrupter breaks the electric current to the motor when the lever is in its lowest position. The length of time that the fruit was exposed to the washing solution was readily governed by the number of impulses of the plunger shaft and controlled by the use of the hand lever.

Solution tanks are constructed of wood, with inside dimensions of eighteen inches square and fifteen inches deep. A thermometer guard was constructed in one corner of each tank. The structure of these guards permitted using partially submerged, floating thermometers, and also free circulation of the solutions. The solution in the first and third tanks was heated by circulating through acid resisting coils extending from back of the tanks over gasoline burners (Fig. 2).

FRUIT USED IN THE EXPERIMENTS.—The apples used in the experiments were grown and sprayed in the Wenatchee and Yakima districts of the state of Washington. The fruit of lots bearing the legend letters A, B, C, W, and Z, was grown and sprayed in Wenatchee, and the fruit of lots H and L was from Yakima. Natural cryolite was included in the spray programs in various numbers of applications (Table 1).

All of the fruit used had been placed in cold storage within a few weeks after picking, being removed approximately a week before the washing experiments were made.

PREPARATION OF WASHING SOLUTIONS.—In preparing the washing solutions, approximately 12 gallons of water were put into the first and the last tanks of the experimental washer. A weighed amount of a stock solution of commercial sodium silicate (1 $Na_2O$:1.61 $SiO_2$) was thoroughly mixed into the water of the first tank. The concentration of this solution was then determined by titrating a 25 ml. aliquot with a 0.1 normal solution of hydrochloric acid in the presence of methyl orange as an indicator and calculated on the basis of per cent by weight.

If any wetting agent, with the exception of soap bark, was to be added to the hydrochloric acid or the sodium silicate solution, it was made into a paste with a small amount of solution before being mixed with the contents of the tank. In the case of the soap bark, the powdered product was put into a small cloth sack and attached to the bottom of the container of the fruit washer. The container was then lowered into the sodium silicate or hydrochloric acid solution, as the case may be, and the machine operated for three hours with the solution at a temperature of 110° F. before any washing experiments were made. After the addition of any wetting agent, the solution of sodium silicate or hydrochloric acid was rechecked for concentration.

**Table 1.—Description of the apple samples.**

| LEGEND | VARIETY | ORIGINAL RESIDUE[1] AS GRAINS FLUORINE PER LB. OF FRUIT AFTER HARVEST | Spray Program[2] (Lead Arsenate used as a calyx spray in each case) |
|---|---|---|---|
| A | Winesap | .29 | 1st cover spray: lead arsenate (3 lbs.+$\frac{1}{6}$ lb. colloidal spreader[3])<br>2nd cover spray: lead arsenate (3 lbs.+1$\frac{1}{2}$ pts. mineral oil spreader[4])<br>3-4-6-7-8-9th cover sprays: natural cryolite[5] (3 lbs.+1 pt. fish oil[6]) |
| B | Winesap | .22 | 1-2nd cover sprays: same as for legend A.<br>3-4-5-6th cover sprays: natural cryolite (3 lbs.+1 pt fish oil) |
| C | Delicious | .32 | Same as for legend A. |
| H | Winesap | .12 | 1-2-3rd cover sprays: lead arsenate (3 lbs.+$\frac{1}{2}$ gal. mineral oil emulsion[7])<br>4-5th cover sprays: lead arsenate (3 lbs.+1$\frac{1}{2}$ pts. mineral oil spreader[8])<br>6-7th cover sprays: natural cryolite (3 lbs.+$\frac{1}{2}$ gal. mineral oil emulsion) |
| L | Winesap | .14 | 1-2-3-4-5th cover sprays: same as for H.<br>6-7th cover sprays: natural cryolite (3 lbs.+1$\frac{1}{2}$ pts. fish oil) |
| W | Jonathan | .31 | 1st cover spray: lead arsenate (3 lbs.+2 qts. kerosene, $\frac{1}{4}$ lb. ammonium oleate)<br>2-3-4-5th cover sprays: natural cryolite (3 lbs.+$\frac{1}{2}$ gal. mineral oil,[9] $\frac{1}{4}$ lb. triethanolamine oleate and 2 oz. of zinc sulphate) |
| Z | Jonathan | .16 | 1st cover spray: same as for legend W.<br>2-3rd cover sprays: calcium arsenate (4 lbs.+$\frac{1}{2}$ gal. mineral oil, $\frac{1}{4}$ lb. triethanolamine oleate, and 3 oz. of zinc sulphate)<br>4-5th cover sprays: same as legend W. |

[1] Average of duplicate analyses.
[2] The figures given are for the amount of material used to each 100 gallons of spray.
[3] *Fluxit*, mfg. by the California Spray Chemical Co. of California.
[4] *Orthex*, mfg. by California Spray Chemical Co. of California.
[5] *Kryocide*, mfg. by the Pennsylvania Salt Mfg. Co. of Philadelphia.
[6] Herring oil having a cloud point not over 65° F. Iodine number approx. 135. Fatty acid content 1–2%.
[7] *Trecol*, mfg. by Oil Sprays, Inc., Yakima, Washington.
[8] *Trestick*, mfg. by Oil Sprays, Inc.
[9] Viscosity approx. 75 seconds Saybolt. Unsulfonated residue not less than 90%.

In the center tank of the washer, fresh running water was maintained at all times by means of an overflow through a half-inch pipe.

SAMPLING AND ANALYZING FOR FLUORINE SPRAY RESIDUES.—One sample of ten fruit was taken from each washing lot for chemical analysis. An attempt was made to keep the size of the fruit similar and bring the average weight to approximately 1400 grams. In making analyses of fruit used in washing method comparisons, it was believed advisable to have an

equal number of fruit in each sample, as past experience has shown that the stem and calyx end of the washed fruit may contain the greatest portion of the spray residue.

The method for determining the quantity of fluorine[1] on the fruit was developed by the Food and Drug Administration (1937). In this procedure the organic matter in the sample, in the case of analyzing apples, is greatly reduced by using only the skin, stem and calyx portions of the fruit.

The selected fruit samples taken for lead spray residue analyses were submitted to a commercial laboratory specializing in spray residue analytical work.

EXPERIMENTAL PROCEDURE.—The fruit washing experiments were made during the middle of December, and the temperature of the room ranged from 35° to 45° F.

Each sample consisted of twenty fruits, carefully selected for size from several bushels. The unwashed samples were collected in clean paper bags so as to be in readiness for the washing operations. In this manner it was not necessary to handle unwashed fruit, as it was readily emptied from the paper bags into the fruit container of the washer.

A level of from 8 to 8.5 inches, equivalent to approximately 11.5 gallons was found most satisfactory in the tanks. Any solution in excess, therefore, was removed and stored in non-corrosive containers for use in replacement of any solution lost from carry-over or evaporation.

The steps in the washing procedure may be summarized as follows: 1. Checking operating mechanism; 2. Checking of the solutions for strength; 3. Adjustment and checking of temperatures; 4. Introduction of fruit sample into container of experimental fruit washer when it is in the highest position over tank, in which fruit is to be subjected to first treatment; 5. Exposure of fruit sample to washing solutions and rinses; 6. Removal of sample from container to wooden rinse box for supplementary rinse; 7. Collecting of washed fruit sample in clean, labelled paper bags.

The length of exposure of the fruit to each washing solution is controlled by the number of impulses of the fruit container. In these experiments for treatment in either the alkaline or the acid solution, each sample was subject to eighteen impulses of the container, which is equivalent to approximately forty seconds of exposure. A double washing process was used throughout the experiments. The fruit was first treated in the sodium silicate solution, followed by 35 seconds rinse treatment in the center tank. It was then treated in the hydrochloric acid solution and returned to the center tank for another 35 seconds rinse treatment.

The sample was removed from the container after the final rinsing treatment in the center tank to a varnished wooden box having a bottom perforated with one-fourth inch holes. This box was then placed over a drain and the contents subjected to an added rinse with one gallon of cold, fresh water. Each sample was similarly rinsed. After the excess water had drained from the sample it was transferred to a paper bag which was later taken to cold storage.

DISCUSSION ON WETTING AGENTS USED.—The equivalent amount of the various wetting agents used on the basis of 100 gallons of solution is given in table 2. All of the wetting agents used in the experiments, with the exception of soap bark, were identified by trade names.

*Soap Bark* (*Quillaja*); a coarse, light tan, powder. In the sodium silicate solution, the presence of the soluble ingredients of soap bark failed to produce foaming on agitation. When added to the hydrochloric acid solution, a good foam was produced when agitated.

Although it is included as a wetting agent in these experiments, soap bark is probably better known as a detergent and emulsifying agent. These properties are attributed by Wood & LaWall (1926), principally to two ingredients which belong to the group of saponins, one of which is said to be identical with senegin and the other with quillaic acid. The saponins occur in varying amounts in a wide variety of plants, the more important sources being the inner layers of the bark of *Quillaja saponaria* Milina (soap bark) and the pericarp of the fruit of *Sapindus utilis*, Martin (1940). The saponins form a group of glucosides which can on hydrolysis or by the action of specific enzymes be converted into sugars and sapogenins.

[1] Acknowledgement is made to Mr. George Skaer who assisted in making the fluorine spray residue determinations.

The wetting properties of saponins were demonstrated by Taubman (1930), in experiments on the wetting of paraffin by water. He found that when the saponin concentration of aqueous solutions reached 0.01 per cent, paraffin could be wetted. The possibilities of saponin (soap bark) as a component in the acid solvent system for dissolving pulverized natural cryolite was suggested in a report by Riggs.[1] In preliminary laboratory experiments, Garverich,[2] found that the amount of powdered natural cryolite dissolved in 100 cc. of a saturated solution of soap bark extract containing 4.5 cc. of 20° Baumé hydrochloric acid was greater than in 100 cc. of a 1.0 per cent *Vatsol* solution containing the same amount of hydrochloric acid.

*Intramine-Y;* a soft, yellowish-tan powder, possessing a slight odor of coconut oil. It appeared to be readily soluble in the sodium silicate solution and produced a good suds. When added to the hydrochloric acid, it produced a light milky solution which also had good foaming qualities.

According to Antwerpen (1939) and Cupples (1940), the *Intramine* type of wetting agent is a sodium salt of sulfonated lauryl and myristyl collamide and finds use as a detergent, wetting or emulsifying agent in the textile and cosmetic industries.

*Nekal BX;* a fine, buff colored powder which becomes sticky and darker in color upon exposure to the atmosphere. It was soluble in the sodium silicate solution and produced a good suds. When added to the hydrochloric acid solution, it imparted a light, milky color, and foamed well upon agitation.

The chemical composition of *Nekal BX* is given as sodium alkyl naphthalene sulfonate (Roark 1937). The same composition for *Nekal BX* is given by Antwerpen (1939) and Cupples (1940). The appearance of the product is described by Cupples as a fine powder, having a light-tan color.

*Vatsol;* a buff colored powder which like *Nekal BX* becomes sticky and darker in color when exposed to the atmosphere. *Vatsol* seemed to be compatible with the sodium silicate solution and formed a good suds on agitation. When it was added to the hydrochloric acid, it produced a light, opalescent solution which also formed a good suds upon agitation.

Martin (1940), classifies *Vatsol* as one of the proprietary products along with *Nekals*, *Alkanols*, *Invadines*, etc. of a group having as their active constituents the iso-propyl and butyl naphthalene sulfonates, which are characterized by the ready solubility of their metallic salts.

Where *Vatsol* was added to 1.5 per cent solutions of hydrochloric acid, with and without 2 per cent sodium chloride, in both a flood and a flotation type fruit washer, the results of Smith & Ryall (1933) and others, showed that while there was more complete removal of lead and arsenic, the effectiveness for removing fluorine from fruit was not increased, and in some cases was decreased. The results obtained by Hough (1936), on the removal of fluorine spray residues from fruit sprayed with cryolite, showed that the use of *Vatsol* in either heated or unheated acid solutions of a flotation type fruit washer did not result in increased effectiveness, but did indicate a tendency to reduce the efficiency of the acid wash.

*Hydralene;* a soft, light tan, fibrous powder, which becomes sticky and darker in color when exposed to the atmosphere. The foaming quality of sodium silicate solutions containing *Hydralene* was almost nil. On the other hand, *Hydralene* mixed satisfactorily with the hydrochloric acid solution, producing a foggy, amber colored liquid which had good foaming properties.

The product *Hydralene* is a detergent and wetting agent belonging to the *Nacconol E* type.[3] The chemical composition of the latter product, according to Antwerpen (1939), is sodium alkyl aryl sulfonate.

DISCUSSION OF RESULTS.—The quantity of wetting agent used in the washing solution of the improved type of flotation machine varies somewhat in commercial practices, depending upon the condition and treatment of the fruit. In these experiments, each wetting agent, with the exception of soap bark, was used at the

[1] Riggs, W. S. 1934. Determination of the compatability and effects of *Vatsol*, an organic detergent, on the solubility of natural cryolite in various aqueous systems. Unpublished data. R. & D. Dept., Penn. Salt Mfg. Co., January 20.

[2] Garverich, E. S. 1934. Determination of the effect of saponin and *Vatsol* on the solubility of natural cryolite in various aqueous solutions. Unpublished Report. R. & D. Dept., Penn. Salt Mfg. Co., January 30.

[3] Personal Communication.

rate of 4 pounds to each 100 gallons of solution (Table 2). It was believed that this quantity would give the best comparison of the commercial wetting agents where only one concentration was to be used. In the case of soap bark, twice the amount was used due to the fact that not all of this material is soluble in water.

still noticeable even in the presence of a natural cryolite deposit. It is hardly possible, however, to arrive at a definite conclusion on this point since the average lead residue of the unwashed fruit of lots H and L was only 0.05 grains per pound.

With the exception of *Hydralene*, there is no definite indication that the addition

**Table 2.—Results of the fruit washing experiments on the removal of fluorine and lead spray residues.**[1]

| Washing Treatment | | | Fluorine Residue Grains 1 lb. of Fruit | | | | | | | Lead Residue[2] Grains/lb. of Fruit | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st Wash: SS 9.6% 40 seconds at 110° Fah. | 2d Wash: HCl 1.5% 40 seconds at 110° Fah. | Legend | A | B | C | H | L | W | Z | H | L |
| | | | *Before Washing* | | | | | | | *Before Washing* | |
| | | | .29 | .22 | .32 | .12 | .14 | .31 | .16 | .05 | .03 |
| | | | *After Washing* | | | | | | | *After Washing* | |
| No WA added | No WA added | | .022 | .012 | .018 | .010 | .012 | .029 | .011 | .011 | .012 |
| No WA added | 8# Soap Bark | | .023 | .017 | .027 | .014 | .015 | .036 | .012 | .009 | .009 |
| | 4# *Intramine-Y* | | .051 | .020 | .035 | .026 | .017 | .043 | .012 | .005 | .010 |
| | 4# *Nekal BX* | | .052 | .033 | .085 | .032 | .037 | .050 | .018 | .009 | .009 |
| | 4# *Vatsol* | | .046 | .037 | .063 | .045 | .040 | .072 | .065 | .004 | .003 |
| | 4# *Hydralene* | | .060 | .024 | .080 | .033 | .029 | .046 | .036 | .010 | .005 |
| 8# Soap Bark | No WA added | | .017 | .015 | .018 | .015 | .011 | — | — | — | — |
| 4# *Intramine-Y* | | | .018 | .017 | .019 | .011 | .011 | — | — | — | — |
| 4# *Nekal BX* | | | .021 | .016 | .020 | .013 | .015 | — | — | — | — |
| 4# *Vatsol* | | | .022 | .017 | .020 | .015 | .017 | — | — | — | — |
| 4# *Hydralene* | | | .030 | .030 | .034 | .034 | .018 | — | — | — | — |

[1] All fluorine analyses made in laboratory of the Pennsylvania Salt Mfg. Co. of Washington, Tacoma, Wash.
[2] Lead analyses made by Yakima Industrial Laboratories, Yakima Wash.
SS = Sodium Silicate, having an equivalent ratio of $Na_2O$ to $SiO_2$ of 1:1.6.
HCl = Hydrochloric Acid
WA = Wetting Agent

*Hydralene*—Manufactured by National Aniline & Chemical Co.
*Intramine-Y* = Manufactured by Synthetic Chemicals, Inc.
*Nekal BX*—Manufactured by General Dyestuff Corporation
*Vatsol*—Manufactured by American Cyanamid & Chemical Corporation

Probably the most apparent result of these experiments is that the addition of any one of the wetting agents tried did not show any inclination to improve the effectiveness of the acid wash (Table 2).

The depressing effect caused by the addition of a wetting agent to the acid wash in the removal of fluorine spray residue is in marked contrast to that obtained in the removal of lead spray residues by the same treatment. It is particularly interesting in the case of the fruit of lots H and L on which the lead tests were made, since these lots had been sprayed twice with natural cryolite following five applications of lead arsenate (Table 1). This would seem to indicate that the advantages of using a wetting agent in the acid wash for the removal of lead residue were

to the sodium silicate solution of any of the wetting agents tried would affect the efficiency of the alkaline-acid washing treatment. When *Hydralene* was present in the sodium silicate solution, (Table 2), the results of the alkaline-acid treatment were higher in every case. This may be due to the behavior of *Hydralene* in sodium silicate solutions as previously described in the behavior of wetting agents.

A double washing treatment was used throughout the experiments since this is the general practice in commercial fruit washing in the Pacific Northwest. The sodium silicate and hydrochloric acid solutions were used at concentrations most commonly employed. In the washing tests a wetting agent was never used in both the alkaline and acid solutions at the same

time in the various double washing treatments tried, so that the effect of the added material in either solution would be more noticeable.

With the exception of soap bark extract, all of the wetting agents tried in this experiment produced some precipitation in various degrees in hydrochloric acid solutions used for washing cryolite sprayed fruit. There is a possibility that the presence of these wetting agents in the acid solution resulted in the forming of a coating on the cryolite particles, capable of inhibiting the normal action of the acid.

Smith *et al.* (1933, 1934), reported that when an acid-wetting agent combination was used for washing fruit which had been sprayed with cryolite, more washing injury occurred on the fruit probably due in part to the fact that the acid-wetting agent combination is more difficult to rinse off, and emphasize the need for added rinse when a wetting agent is used.

In these experiments, no washing injury could be found on the fruit, with the exception of lot Z. On this lot the injury was typical spray burn and the same injury was found on the unwashed fruit. This fruit was sprayed with calcium arsenate for the second and third cover sprays (Table 1).

SUMMARY.—Experiments were made on the removal of fluorine spray residues from fruit sprayed with natural cryolite. Each of the following wetting agents: soap bark extract, *Intramine-Y*, *Nekal BX*, *Vatsol*, and *Hydralene*, was used in either the sodium silicate or the hydrochloric acid solution of a double process washing schedule.

The sodium silicate concentration was maintained at 9.6 per cent by weight of the actual compound[1] in the solution used for the first washing treatment. The hydrochloric acid concentration in the solution used for the second washing treatment was maintained at 1.5 per cent actual HCl by weight. Every sample of fruit was exposed to each washing solution for forty seconds at a temperature of 110° F. in a positive control, experimental fruit washer of a flotation type.

The addition of either, soap bark, *Intramine-Y*, *Nekal BX* or *Vatsol* to the sodium silicate solution did not cause any particular change in the result obtained by the dual washing treatment. When *Hydralene* was added to the sodium silicate solution, the effectiveness of the washing treatment was noticeably lowered.

The addition of any one of the wetting agents to the hydrochloric acid solution reduced the effectiveness of the washing treatment. With the exception of soap bark, this reduction in effectiveness was considerable.—8-18-41.

[1] $Na_2O.1.61SiO_2$. A concentration of 9.6 per cent is equivalent to about 80 pounds per 100 gallons of solution.

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# Present Status of Rotenone and Rotenoids

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One of the most amazing developments in American agriculture during the past decade has been the rapid growth in the use of derris, cube, timbo, and barbasco as insecticides. These plants, all closely related botanically and belonging to the family Fabaceae, owe their toxicity to rotenone and a group of structurally related compounds called rotenoids.

Proprietary insecticides containing derris extractives were manufactured in Great Britain as early as 1911 and were imported into the United States about 1915. Derris root was not brought into this country in commercial quantity until 1931. The trade then grew rapidly; in 1932 the importation was 17 long tons and in 1933, 257 long tons. Cube, which is *Lonchocarpus* of Peruvian origin, became commercially available in the United States in 1931, the total importation in that year amounting to 3,979 pounds. Timbo, which is *Lonchocarpus* of Brazilian origin, was first imported in significant quantity in 1935, in which year 154,323 pounds were brought in from the state of Para, Brazil. The first official figures on the importation of *Lonchocarpus* are for the year 1936. Table 1 presents the data on both *Derris* and *Lonchocarpus* for the years 1936 to 1940, inclusive.

The magnitude of these figures is better appreciated when they are converted into pounds of insecticidal material as applied in the field. Most of the derris, etc., is used in the form of a dust made by diluting the powdered root to a rotenone content of 1 per cent. Assuming a rotenone content of 4 per cent in the imported root (and much of it contains 8 to 10 per cent rotenone), the 6½ million pounds of crude and powdered root imported in 1940 would make over 25 million pounds of insecticidal dust.

THE CULTIVATION OF ROTENONE-BEARING PLANTS.—Of the more than 80 species of *Derris*, only two are cultivated, *Derris elliptica* Benth. and *D. malaccensis* Prain (Great Britain Imperial Institute, 1940).

*Derris elliptica* is found in the Malay Peninsula, the East Indian Archipelago, and the Philippines. In the natural state it is a woody climber of large size, bearing clusters of pale rose-pink flowers which turn to buff as they age. The mature pods are about 2 inches long and 1 inch wide and olive brown to dark brown in color; they contain usually one but sometimes two or three seeds. In some areas, notably the Malay Peninsula, the plant rarely flowers, a fact that has led some observers to believe that the species is not really native to the Peninsula but may have originated from stock imported from southern China. In Java, however, the same species flowers freely even when the plants are comparatively young.

Of the cultivated forms of this species, Changi No. 3 is one of the more important. The plants are prostrate with the stems trailing but not forming a dense cover and without erect woody side shoots. The plants are strong and vigorous and remarkably free from attack by insect pests. On a moisture-free basis their roots, when 15 months old, averaged 12 to 13.5 per cent rotenone and nearly 30 per cent ether extract; an individual plant from one of the better clones contained as much as 15.25 per cent rotenone.

*Derris malaccensis*, which grows in the Malay Peninsula, differs from *D. elliptica* in habit and in other ways. The cultivated form has come to be regarded as a separate variety, *D. malaccensis* var. *sarawakensis* Hend. The roots of this species contain little or no rotenone but average 19 per cent or more ether extract.

Table 1.—Imports of rotenone-bearing roots into the United States.[1]

| Items and Country of Origin | 1936 | | 1937 | | 1938 | | 1939 | | 1940 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds | Value | Pounds | Value | Pounds | Value | Pounds | Value | Pounds | Value |
| Derris root, crude: | | | | | | | | | | |
| British Malaya | 332,251 | $ 69,182 | 401,975 | $72,613 | 583,035 | $68,279 | 1,877,800 | $196,159 | 1,842,087 | $195,286 |
| Philippine Islands | 149,505 | 21,626 | 110,528 | 14,046 | 23,391 | 3,263 | 228,632 | 20,360 | 229,465 | 17,520 |
| British India | — | — | — | — | — | — | 10,972 | 996 | — | — |
| Netherlands Indies | 28,581 | 5,145 | 57,524 | 10,609 | 136,235 | 21,617 | 184,575 | 27,952 | 996,845 | 132,430 |
| French Indochina | — | — | — | — | — | — | 33,069 | 3,968 | 143,911 | 13,968 |
| British East Africa | — | — | — | — | — | — | — | — | 8,664 | 1,368 |
| Other British Indies | — | — | 314 | 63 | — | — | — | — | — | — |
| United Kingdom | — | — | 2,257 | 449 | — | — | — | — | — | — |
| Panama | — | — | 54 | 11 | — | — | — | — | — | — |
| Total | 510,337 | 95,953 | 572,652 | 97,791 | 742,661 | 93,159 | 2,335,048 | 249,435 | 3,220,972 | 360,572 |
| Cube, timbo, or barbasco root, crude: | | | | | | | | | | |
| Brazil | 508,570 | 34,044 | 197,892 | 16,677 | 58,979 | 2,879 | 146,365 | 9,477 | 387,413 | 28,580 |
| Colombia | 1,200 | 156 | — | — | — | — | — | — | — | — |
| Peru | 171,600 | 19,350 | 378,259 | 37,487 | 476,760 | 32,777 | 1,640,964 | 128,141 | 2,225,347 | 185,840 |
| Venezuela | 22,750 | 1,775 | — | — | 55,115 | 8,167 | 119,865 | 16,728 | 74,163 | 10,546 |
| Total | 704,120 | 55,325 | 576,151 | 54,164 | 590,854 | 43,823 | 1,907,194 | 154,346 | 2,686,923 | 224,966 |
| Derris, cube, timbo, or barbasco, advanced in value (dutiable): | | | | | | | | | | |
| Brazil | 1,124,936 | 172,239 | 1,263,773 | 190,844 | 1,733,755 | 245,391 | 838,717 | 107,347 | 658,920 | 85,896 |
| Netherlands Indies | — | — | — | — | — | — | 18,032 | 5,095 | — | — |
| Philippine Islands | — | — | — | — | — | — | 33,171 | 2,775 | — | — |
| United Kingdom | — | — | — | — | 2,240 | 828 | 6,720 | 2,154 | — | — |
| Total | 1,124,936 | 172,239 | 1,263,773 | 190,844 | 1,735,995 | 246,219 | 896,640 | 117,371 | 658,920 | 85,896 |
| GRAND TOTAL | 2,339,393 | 323,517 | 2,412,576 | 342,799 | 3,069,510 | 383,201 | 5,138,882 | 521,152 | 6,566,815 | 671,434 |

[1] From data furnished by the U. S. Department of Commerce, Bureau of Foreign and Domestic Commerce.

In the Netherlands Indies a variety of *Derris elliptica* called Toeba woeloeng L.C.B. is grown, which has yielded over 10 per cent rotenone. This variety is similar morphologically to Changi No. 3, and it is possible that the two may be identical.

In the Philippines derris root averages 4 to 5 per cent rotenone. Although derris is found in French Indo-China, Ceylon, Polynesia, and Brazil, the rotenone content of the roots is usually low and little use is made of them commercially.

The yield of dried derris roots ranges from 800 to 1,800 pounds per acre, according to Sievers (1940).

The Imperial Institute of Great Britain (1938) has reviewed information on the cultivation of *Lonchocarpus*, of which about 70 species are known. The most important species entering commerce from Peru, where it is known as cube, is *Lonchocarpus utilis* A. C. Smith. The bulk of the timbo exported from Brazil is *L. urucu* Killip and Smith. The *Lonchocarpus* originating in Venezuela is called barbasco, but it must be remembered that this word means fish poison and is applied in Spanish-speaking countries to many plants that do not contain rotenone.

*Lonchocarpus* plants in the natural state are large, woody climbers which may reach the tops of tall trees, but usually under cultivation they are not allowed to remain after about four years, up to which age they have a bushy form.

The rotenone content of cube and timbo is exceedingly variable. Much of the material contains 8 to 10 per cent rotenone, and specimens containing 15 per cent have been analyzed by the Division of Insecticide Investigations. In the United States commercial cube and timbo powders are blended to the same rotenone content (4 or 5 per cent) as is derris powder.

The yield of fresh timbo roots harvested $3\frac{1}{2}$ years after planting is stated to be $17\frac{1}{2}$ metric tons per hectare. Assuming that the roots lose 60 per cent of their weight on drying, this is equivalent to about 6,000 pounds of dried roots per acre.

At present none of the 150 species of *Tephrosia* is grown commercially for use as an insecticide. V. A. Little, of the Texas Agricultural College at College Station, Texas, and A. F. Sievers, of the Bureau of Plant Industry, United States Department of Agriculture, are conducting a cooperative investigation of the possibilities of the devil's shoestring (*T. virginiana*) as a source of insecticide. The rotenone content of the roots of some plants is as high as 4 or 5 per cent. It is believed that about 1,000 pounds of dried roots per acre can be grown on the sandy infertile soils of eastern Texas.

Although *Derris*, *Lonchocarpus*, and *Tephrosia* grow wild in many countries, practically all the plants entering commerce are cultivated. Plants growing in the jungle are so inaccessible and also so variable in rotenone content that they cannot compete with plantation-grown material that has been carefully selected for a high content of active principles. Moreover, with the exception of the devil's shoestring, rotenone-bearing plants cannot be grown in the United States. At present we must look to the tropics for our supply of rotenone and the rotenoids.

INSECT PESTS OF DERRIS, CUBE, AND TEPHROSIA.—Although the rotenone-bearing plants are potent insecticides, they are attacked by a surprisingly large number of insect enemies. Roark (1939) has compiled a list of 45 identified and 13 unidentified species of arthropods attacking derris. These species belong to 5 orders, 26 families, and 39 genera. The fact that dried roots in storage are attacked by 19 species of Coleoptera illustrates the the high specificity of action of rotenone against insects. That the leaves of growing derris are attacked by caterpillars and other insects is not so surprising, because the insecticidal principles of the plant are not found in the leaves.

Only 3 species of insects have been recorded as attacking *Lonchocarpus* (Roark 1936, 1938b). One of these, *Dinoderus biforeolatus* Woll., attacks derris root also.

*Tephrosia* is also subject to injury by many insects. *T. virginiana* is attacked by at least 9 species, and some of these feed on the seeds which are rich in rotenone (Roark 1937).

From a practical standpoint the insect enemies of these plants do not seriously interfere with their successful cultivation, and borers in dried roots are easily controlled by heating or fumigation.

CHEMISTRY OF DERRIS, CUBE, TIMBO, AND TEPHROSIA.—The following compounds have been found in derris root: Rotenone, levodeguelin, levo-alpha-toxicarol, elliptone, sumatrol, and malaccol.

All of them have been isolated in optically active crystalline form except deguelin, which has been obtained only in the inactive form. An optically active dihydrodeguelin was obtained by Haller & La-Forge (1934) by hydrogenating a derris extract. Tephrosin, formerly thought to be present in derris root, is now known to be formed by the oxidation of deguelin during its isolation.

Of the known constituents of derris root only two, rotenone and levodeguelin, have noteworthy toxicity to insects. Certain other constituents, for example, toxicarol, are highly toxic to goldfish but only feebly so to insects.

The insecticidal constituents of *Lonchocarpus* and *Tephrosia* have not been so thoroughly studied as have those of *Derris*, but rotenone and deguelin are known to be present. Toxicarol was first isolated from *T. toxicaria*, but it has never been found in *Lonchocarpus*.

Jones (1939) reported the presence of a minute quantity of alkaloidal material in derris, cube, and timbo roots. This material proved nontoxic to mosquito larvae at a concentration of 1:10,000.

Although their structure is fully known, rotenone and rotenoids have not been synthesized and there is little likelihood of this being accomplished. None of the compounds of analogous structure that have been prepared have insecticidal value, and the only derivative of rotenone possessing toxicity is dihydrorotenone. We shall be compelled to depend upon certain leguminous plants for our supply of rotenone and the rotenoids for some time to come.

Methods are now available for accurate chemical analyses of rotenone and deguelin, separately and together. Rotenone is best determined by extracting the finely powdered root with chloroform, converting the rotenone in the extract to the solvate it forms with carbon tetrachloride, and filtering and weighing this compound, $C_{23}H_{22}O_6 \cdot CCl_4$, the rotenone content of which is 72 per cent (Jones & Graham 1938). This method has been adopted as "official, first action" by the Association of Official Agricultural Chemists.

The red color test of Goodhue (1936) is used to determine rotenone plus deguelin in an extract of derris, cube, timbo, or *Tephrosia*.

Jones (1941) has recently prepared a review of all chemical methods that have been proposed for the evaluation of rotenone-bearing plants.

PHARMACOLOGY OF ROTENONE AND THE ROTENOIDS.—A great deal of work has been done on the pharmacology of rotenone and the rotenoids. Geoffroy (1892) tested pure rotenone extracted from *Lonchocarpus nicou* upon frogs and rabbits. The early work on the pharmacology of *Lonchocarpus* has been referred to by Roark (1936, 1938b), who also reviewed the pharmacology of *Tephrosia* (Roark 1937). Haag (1941), has recently completed an exhaustive review of the pharmacological literature on rotenone and related compounds. The following information is taken mostly from this work.

When finely powdered undiluted derris (rotenone content 9.6 per cent) is applied to the human skin, mild irritation is sometimes produced, particularly where two skin areas touch. This local reaction has practically always disappeared within 24 hours after removal of the material. Grinders of derris and cube roots guard against irritation by requiring their employees to bathe frequently and to wear clothing designed to minimize contact with the dust. Derris, as well as rotenone, also produces a sensation of numbness on the mucous membranes of the mouth and throat, which lasts for three or four hours.

Derris (or rotenone) administered to laboratory animals (dogs and cats) by mouth, by vein, or by inhalation promptly caused nausea and vomiting, even when dose was so small as to provoke no other appreciable physiological response. This emetic action should have some practical significance, because individuals having inadvertently ingested derris would in all probability expel much of the material.

As the result of laboratory feeding tests upon guinea pigs, white rats, and rabbits, Haag concluded that the toxicity of derris does not depend solely upon its rotenone content. For example, the acute toxicity of derris powder (9.6 per cent rotenone) when fed to rabbits was 5 times that of pure rotenone. The acute toxicity of lead arsenate when fed to rabbits is 30 times, of nicotine 100 times, and of strychnine 700 times that of rotenone.

Haag & Taliaferro (1940) found that the growth of young male rats was not affected when cube (4.7 per cent rotenone and 19.7 per cent total extractives) was administered in food in amounts up to 300

parts per million for 150 days. The danger of chronic poisoning from the daily consumption of foodstuffs treated with rotenone-bearing sprays or dusts is remote.

Cassil (1941), in an analytical and statistical study of derris residue on marketable cabbage, has shown that five applications of derris-clay dust (1 per cent rotenone) at the rate of 20 pounds per acre gave an average derris residue of 36.5 parts per million before rain. The residue dropped to 3.6 parts per million after rain, and when the outer leaves had been stripped to produce "U. S. No. 1 stripped" the residue was only 1.9 parts per million. Statistical calculations show that among 11,600 heads from a single acre, one U. S. No. 1 head might be encountered that would contain 73 parts per million of derris (4.1 per cent rotenone, 15.1 per cent chloroform extract).

On the basis of Cassil's findings it may be calculated that a man weighing 154 pounds (70 kg.) would have to eat about 110 pounds (50 kg.) of cabbage bearing a derris residue of 73 parts per million to get an acutely toxic dose. The Bureau of Entomology and Plant Quarantine recommends for the control of cabbage worms, the Mexican bean beetle, and certain other vegetable insect pests, a dust made from talc or clay and powdered derris and containing not more than 1 per cent of rotenone. For a man to get an acute toxic dose of this dust he would have to eat 360 grams of it. It is doubtful if one could swallow this quantity of material even with suicidal intent, because one of the first effects of derris is vomiting. Derris residues on foodstuffs are not a menace to health, for three reasons: (1) The amount present even immediately following application is small; (2) this residue, small as it is, is rapidly reduced by weathering, because derris adheres poorly as compared with lead arsenate; (3) rotenone and the other constituents in the derris are rapidly decomposed by exposure to sunlight and air and the decomposition products are nontoxic.

**Table 2.—Number of identified families, genera, and species of Insecta and Acarina against which rotenone and the rotenoids have been tried, arranged according to order.**

| Order | Families | Genera | Species | References |
|---|---|---|---|---|
| Collembola | 3 | 4 | 4 | 8 |
| Orthoptera | 5 | 13 | 13 | 49 |
| Dermaptera | 1 | 1 | 1 | 3 |
| Odonata | 1 | 1 | 0 | 2 |
| Isoptera | 0 | 0 | 0 | 3 |
| Corrodentia | 1 | 2 | 2 | 1 |
| Mallophaga | 4 | 8 | 11 | 33 |
| Thysanoptera | 1 | 12 | 25 | 100 |
| Homoptera | 10 | 55 | 92 | 341 |
| Hemiptera | 8 | 42 | 56 | 106 |
| Anoplura | 3 | 7 | 10 | 35 |
| Coleoptera | 29 | 125 | 189 | 439 |
| Lepidoptera | 42 | 165 | 214 | 553 |
| Hymenoptera | 6 | 29 | 37 | 131 |
| Diptera | 19 | 49 | 79 | 349 |
| Siphonaptera | 4 | 8 | 10 | 47 |
| Acarina | 12 | 27 | 40 | 179 |
| Phalangida | 1 | 1 | 1 | 1 |
| Total | 150 | 549 | 784 | 2,380 |

Use of Rotenone and Rotenoids as Insecticides.—Since 1927 the writer has been compiling information on *Derris*, *Lonchocarpus*, *Tephrosia*, and other plants containing rotenone and the rotenoids. The data on the effectiveness of these insecticidal principles upon the various species of Insecta and Acarina have been classified according to the order, family, and genus to which these organisms belong. This information is to be published in the "E" series of mimeographed publications of the Bureau of Entomology and Plant Quarantine of the United States Department of Agriculture.

The extent to which rotenone and the rotenoids have been tested as insecticides is shown in table 2.

There seems to be no record in the literature of tests with derris against Thysanura, although pest-control operators have doubtless used preparations containing it for the control of silverfish.

Rotenone and the rotenoids are highly toxic to all species of Mallophaga, Anoplura, and Siphonaptera upon which they have been tested. Practically all Hymenoptera except a few ants are also susceptible. The other orders display a wide range in susceptibility from family to family and even among genera of the same family. In the one lepidopterous family Phalaenidae, why should the maize stalk borer, *Busseola fusca* (Fuller), be so susceptible and the southern armyworm, *Prodenia eridania* (Cram.), resistant to rotenone? These questions and many similar ones are for the insect toxicologist to answer.

More Effective Ways of Using Rotenone and the Rotenoids.—At present derris and cube are used mostly in

the form of dusts made by mixing the finely ground roots with talc, clay, pyrophyllite, or other inert diluent. Dusts are also made by impregnating walnut-shell flour, pyrethrum marc, or other material with extractives from these roots. Liquid extracts are made with a water-miscible liquid such as acetone if the solution is to be added to water, or with a water-immiscible liquid such as ethylene dichloride if the solution is to be added to kerosene.

Liquid extracts containing all the extractives from derris or the same extractives from which the rotenone has been removed are used in preparing kerosene-base fly sprays. On account of the low solubility of derris extractives, and especially of rotenone, in petroleum hydrocarbons, it is necessary to use a mutual or supplementary solvent. A large number of liquids have been proposed for this purpose. Information on this subject, which is largely in the patent literature, has been abstracted by Roark (1938a, 1940, 1941). Some suggestions as to possible ways in which these products can be improved will be discussed in the following paragraphs:

*Dusts Made by Diluting Ground Roots.*—Numerous investigators have shown that the particle size of a dust profoundly influences its insecticidal efficacy. For example, Siegler & Goodhue (1939) showed that fine particles (4 microns diameter) of phenothiazine were much more toxic to the codling moth larva than were coarse (45 microns) particles. On the other hand, coarse (18 microns) lead arsenate was somewhat more effective than fine (less than 2 microns). They tested the materials as stomach poisons.

Little work has been done on the influence of particle size of dusts on their effectiveness as contact insecticides, but there is a belief that the finer the dust the more effective it is. Fine particles adhere to the surface of a leaf or fruit better than do coarse particles. Commercial derris and cube powders are ground to meet the specification of 90 per cent through a 200-mesh sieve. It would be possible to produce finer powders by the micronizing process, but to produce a powder as fine as the usual commercial lead arsenate, 86 per cent of which is smaller than 6 microns and 69 per cent smaller than 2 microns, an impregnated dust would have to be used.

There are several disadvantages to the use of a dust made by mixing pulverized root and an inert diluent. *Derris* roots, and also cube, timbo, and *Tephrosia* roots, are tough and fibrous and difficult to grind, and heavy and expensive equipment is required to produce a fine powder. The powdered root is not made up of uniformly sized particles, and the rotenone content of the different-sized particles varies greatly. When blown out of a dusting machine, the fine and coarse particles of a dust separate, that is, the fine particles are carried much farther than the coarse particles. This is the principle utilized in an air-separation mill for segregating and regrinding the coarser particles.

The degree of separation of the different-sized particles in a dust under field dusting conditions is greater than is commonly realized. In the Bureau of Entomology and Plant Quarantine commercial calcium arsenate has been separated into hydrated lime and a fraction high in arsenic by means of an air classifier. When applied in the field, a dust of hydrated lime and copper sulfate monohydrate often separates almost completely into its constituents. It would be of interest to determine to what extent the rotenone-rich and the rotenone-poor particles of powdered derris root separate under field-dusting conditions, and to what extent they separate from the clay, talc, or other diluent employed.

There has been much discussion as to whether it is better to use a high-rotenone or a low-rotenone derris in making a dust. To make 100 pounds of a 1 per cent rotenone dust from derris powder containing 10 per cent of rotenone, 10 pounds of derris powder is required, as compared with 25 pounds from a powder containing 4 per cent of rotenone. Since the ratio of diluent to derris powder is 9:1 in the first product, and 3:1 in the second; it has been argued that a low-rotenone root is preferable because of the greater proportion of active particles in the mixture. Preliminary tests against the pea aphid made in the Bureau of Entomology and Plant Quarantine have failed to substantiate this theory. Furthermore, as pointed out above, all particles of a powdered derris root do not contain the same percentage of rotenone.

Recently Wilson *et al.* (1941), of the University of Wisconsin, studied the

electrostatic charge produced in the process of applying rotenone dusts. They found that dusts producing high charges generally give a greater mortality of pea aphids than dusts producing low charges. Pyrophyllite, flaky tales, calcium carbonate, and gypsum produced high charges, whereas clay produced low charges. When soybean oil was added to dusts, the electrostatic charge could be increased or decreased according to the diluent used. These observations indicate the possibility of increasing the effectiveness of rotenone dusts by choosing the proper diluent and oil or other activating agent.

*Impregnated and Coated Dusts.*—Much of the experimental work with impregnated and coated dusts has been done by manufacturers of proprietary products. In dusts made by mixing the diluent or carrier with a solution of the active principles in a volatile organic solvent, *e.g.*, chloroform, and removing the solvent by evaporation, every particle is covered with some insecticidal material. Moreover the particle size of a diluent such as talc can be more closely controlled than can that of a powdered root. Hence, an impregnated dust can be made uniform as regards particle size and content of rotenone and rotenoids on each particle, and such a product has many advantages over a heterogeneous mixture of inert and active particles of nonuniform size. Investigations of impregnated and coated dusts seem well worth while.

*Solutions in Organic Solvents.*—Very few organic liquids can be used undiluted to spray growing plants or trees without causing injury. The petroleum hydrocarbons of the paraffin series can be so employed provided the dosage is not too great. Unfortunately, the solubility of rotenone and the rotenoids is high in those solvents, such as chloroform, benzene, and other coal-tar hydrocarbons, carbon disulfide, and the esters ethyl formate and ethyl acetate, which cannot safely be applied to living vegetation, and low (at ordinary temperatures) in methanol, ethanol, and petroleum hydrocarbons, solvents that are relatively innocuous to foliage. The solubility of rotenone has been pretty well explored, and there seems little likelihood of finding a good solvent that can safely be sprayed upon plants. We are forced to fall back upon kerosene and light lubricating oils relatively free from phytocidal constituents, adding a small quantity of a better solvent such as acetone and other ketones, safrol, high-boiling ethers, dibutyl phthalate, alkylphenols, etc. Information concerning these is to be found largely in patents. Roark (1938a, 1940, 1941) has published abstracts of this information.

The solubility of rotenone in a highly refined kerosene can be increased from about 0.05 per cent to about 0.20 per cent by weight by the use of a suitable supplementary or mutual solvent. Although this increase in solubility seems slight, the extraordinary toxicity of rotenone makes results of great practical importance. Many of the household fly sprays and cattle fly sprays on the market contain rotenone and the other derris extractives, or these extractives from which the rotenone has been removed, held in solution in a paraffin oil by means of such solvents.

*Colloidal Suspensions in Organic Liquids.*—When a solution of rotenone in chloroform is added to kerosene, the solubility of the rotenone in the mixture of solvents is greater than in kerosene alone but much less than in chloroform alone; hence most of the rotenone will be precipitated in the form of a colloidal suspension. The phenomenon is the same as when an acetone solution of rotenone is added to water. Cressman (in correspondence), for example, has found that a suspension of cube resins in oil is just as effective against the California red scale as a complete solution of cube resins in oil.

There seem to be great possibilities in the use of nonaqueous suspensions of this kind, and a study of their applicability to the control of many insects should pay handsome dividends. The great advantage of a rotenone suspension in oil over a true solution of rotenone in oil is that the concentration of toxicant can thus be vastly increased.

*Colloidal Suspension in Water.*—The original method of using derris as an insecticide was to beat the fresh root to a pulp in water and then spray the milky liquid thus formed upon the plants to be protected. Chinese market gardeners in the Malay Peninsula employed this procedure long before derris was known in Europe or America. The first proprietary insecticides made from derris were liquid

extracts designed to be added to water, and this dilution with water precipitated the active principles in the form of a colloidal suspension. At present most derris sprays are made by suspending the powdered dried root in water rather than by adding a liquid derris extract to water.

The liquid extract offers advantages in the matter of homogeneity of the spray, greater concentration of active principles, and superior wetting and penetrating properties, but these advantages are offset by its higher cost. There seem to be possibilities, however, in the use of improved wetting, penetrating, and activating agents in conjunction with rotenone and the rotenoids, and the incorporation of all these ingredients in the same solution and in the proper proportions ready to be poured into the spray tank offers many advantages. Research to develop better adjuvants for use with derris and cube extractives should prove profitable.

*Suspensions in Air (Smokes and Artificial Fogs).*—Probably the oldest way of combating insect pests is the use of smoke produced by burning grass or brush. It was early found that when cedar wood or cedar leaves, tobacco, and other insecticidal plants were thus burned, the efficacy of the smoke was increased. One of the first methods of using pyrethrum powder was to sprinkle it on a hot stove. Cones made of pyrethrum powder, sawdust, and an oxidizing agent such as potassium nitrate and designed to be burned are on the market. Apparently derris has never been used in this way, although McIndoo & Sievers (1924) reported that when derris and cube were burned the smoke was effective against certain species of aphids.

Recently Goodhue & Sullivan (1941), of the Bureau of Entomology and Plant Quarantine, have investigated the insecticidal possibilities of the smoke made by burning derris and of the fog produced when a liquid derris extract is sprayed upon a heated surface such as an electric hot plate. For example, 0.2 gram of rotenone dissolved in safrol was sprayed upon a heated electric hot plate placed in an 1,100-cubic foot room. The white smoke produced killed 83 per cent of the houseflies in the room.

This method of applying rotenone and the rotenoids has enormous possibilities. By spraying a solution into the exhaust pipe of a tractor or truck, it may be possible to control the pea aphid and many other insects under field conditions. Nicotine dissolved in mineral oil is applied in this way, but the insecticide is in the form of a true vapor or gas whereas in the case of rotenone and other derris extractives which are nonvolatile the insecticide is in the form of solid particles suspended in air.

*Use of Synergists with Rotenone.*—There is a growing tendency to use mixtures of insecticides. Sesame oil (Eagleson 1940) and isobutyl undecylenamide have been shown to increase the insecticidal value of the pyrethrins when mixed with them in solution in kerosene. Other compounds are also suspected to act as synergists, but the proof is not conclusive. With rotenone evidence of synergism is not so clear cut as with the pyrethrins. The possible role of a number of synthetics as synergists for rotenone seems well worth exploring. The so-called activating agents, such as peanut and soybean oils, and various proprietary wetting and penetrating agents may assist the action of rotenone in this manner.—7-1-41.

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# Concentrated Spray Applied With an Autogiro for Control of Cankerworms[1]

R. R. WHITTEN and S. F. POTTS, *U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine,* and E. H. FRANCIS, *National Park Service, U. S. Department of the Interior*[2]

Since 1921 tests have been made in the United States to determine whether defoliating insects can be satisfactorily controlled in woodland areas by the application of insecticides from the air. These tests have been conducted in different parts of the country with both heavier-than-air and dirigible types of airships. Previous to 1936 the insecticides had been applied in the form of dusts. It is believed that the first use of the autogiro in a control project was for applying a liquid insecticide over a woodland area in the National Historical Park at Morristown, N. J., in 1936. That year a heavy infestation of the spring cankerworm, *Paleacrita vernata* (Peck), and the fall cankerworm, *Alsophila pometaria* (Harr.), threatened serious defoliation to most of the trees in this area, and the extensive recreational use of this park made it advisable to adopt measures to control these pests. The size and location of the infested areas and the limited time available made it necessary to adopt a faster method of applying the insecticide than is possible with a truck-drawn sprayer. A privately owned autogiro was equipped to distribute liquid spray and employed for most of the park spray programs of 1936 and 1937. A general description of the autogiro spraying in 1936, including data on the cost and time consumed, has been published (Francis 1936). This paper presents data on the comparative larval feeding and mortality obtained in dusting with the autogiro, spraying with the autogiro, and spraying with a truck-drawn sprayer, as well as data on the spray distribution and adherence obtained with the two types of sprayers.

APPARATUS.—The distributing apparatus used on the autogiro in 1936 is described by Francis (1936). This apparatus consisted of a 54-gallon tank mounted in the front cockpit of the autogiro. From

[1] Cooperative project between the Bureau of Entomology and Plant Quarantine, of the U. S. Department of Agriculture, and the National Park Service, of the U. S. Department of the Interior. C. L. Griswold, C. H. Hoffmann, W. C. Baker, and A. E. Lantz, of the Bureau of Entomology and Plant Quarantine, and George Brady, of the National Park Service, gave valuable assistance in the field work.
[2] Now in private business.

this tank the spray mixture was conducted by gravity to two dispersing units mounted on the undercarriage back of the propeller. Each dispersing unit was rotated by a small 4-bladed propeller, which in turn was driven by the ship's slip stream. The spray mixture entered a hollow collar around the shaft of this small propeller and was conducted back by a screw and discharged into revolving baffle plates constructed at right angles to the shaft and separated by metal strips extending radially from the periphery of these plates nearly to their center. Atomization was accomplished by a film of the fluid flowing at high speed to the edge of these plates, owing to centrifugal force, and then striking a blast of air acting at right angles (Fig. 1).

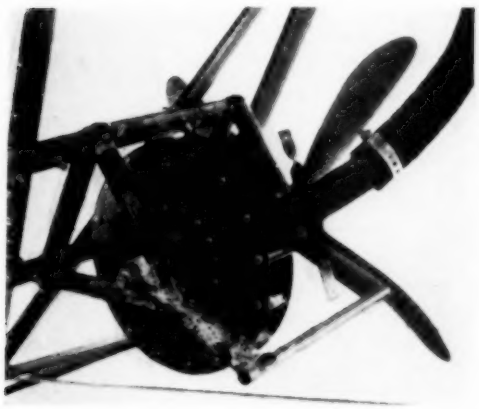

FIG. 1.—Spray dispersing apparatus used on autogiro in 1936.

In 1937 only one dispersing unit was used and it was attached to the center of the undercarriage of the ship. Atomization of the spray was improved by the use of a 10-bladed propeller, which had greater speed and power for turning the atomizing plates than the one previously used (Figs. 2 and 3). An agitator, powered by wind cups, was attached to the reservoir tank to prevent settling of spray materials while the ship was in flight. These changes did not reduce the width of the effective swath.

The truck-drawn sprayer was of a high-pressure type designed for use on woodland and shade trees. It had a tank capacity of 400 gallons. The sprayer was capable of developing 700 pounds' pressure. The spray mixture was agitated continuously during operations.

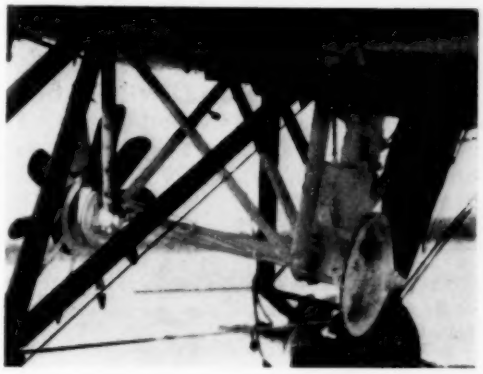

FIG. 2.—Spray dispersing apparatus used on autogiro in 1937.

INSECTICIDE MIXTURES.—For use in the autogiro a spray mixture is required which will remain fluid while in the tank and moist when finely atomized by the distributing unit, and which will adhere well to the foilage (Potts 1939). It is also desirable to reduce the ineffective ingredients to a minimum in order to decrease the weight of the material. The most satisfactory combination for this particular problem consisted of 200 pounds of acid lead arsenate, 10 gallons of fish oil, 6 quarts of light paraffin oil, and 70 gallons of water. The paraffin oil prevented the spray from drying before it reached the foliage. The spray was applied at the rate of about 22 pounds of lead arsenate per acre.

Another spray used in the autogiro was a proprietary colloidal lead arsenate containing lead arsenate equivalent to 11.5 per cent of metallic arsenic. It was ap-

FIG. 3.—Autogiro as equipped to distribute concentrated liquid spray in 1937.

plied at the rate of about 3.6 pounds per acre.

The mixture used in the truck-drawn sprayer contained 5 pounds of lead arsenate, 20 ounces of fish oil, and 100 gallons of water. This material was applied at the rate of about 27.5 pounds of lead arsenate per acre.

The dust mixture consisted of lead arsenate impregnated with 14 per cent by weight of heavy paraffin oil. It was applied at the rate of about 33 pounds per acre.

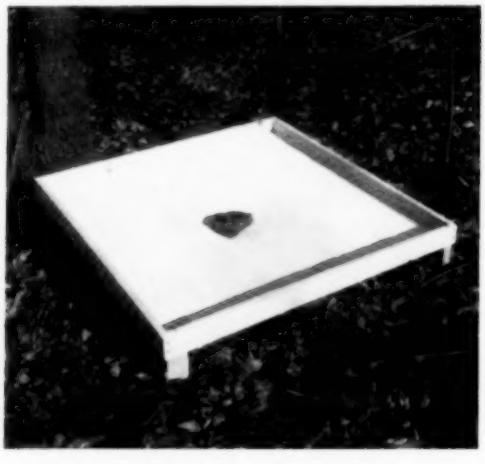

FIG. 4.—Tray used to catch frass and dead larvae that fell from the trees.

METHODS.—Small sample plots were established in representative parts of areas treated by means of the autogiro and the truck sprayer and in an untreated area. The trees in these areas ranged from 50 to 90 feet in height.

To determine the amount of feeding and the mortality, daily collections were made of the frass and the dead larvae that fell from the trees into trays. The trays were yard-square wooden frames with cloth bottoms and were placed at random in each plot and in sufficient number to cover 1 per cent of the ground area. In order that they would be kept level and off the ground, the corners were nailed to wooden stakes driven into the ground (Fig. 4). Each sample of frass was cleansed of foreign matter, desiccated, and weighed to the nearest milligram.

To obtain information on spray distribution and adherence, trees of the principal species present were selected at random in each plot, and leaf samples were taken from the top, middle, and base of each tree immediately after treatment and again after several inches of rainfall. The areas of the leaf samples were measured with a planimeter, and the samples were then digested and quantitatively analyzed for total arsenic trioxide by the Gutzeit method.

In 1936 two daily frass collections were made prior to treatment to measure the comparative infestation in the plots, but in 1937, owing to the earlier time of treatment, such data could not be obtained.

The experimental plots used in 1936 and 1937 are described in table 1.

**Table 1.—Description of plots used in experiments with autogiro and truck-drawn sprayers.**

| Plot No. | Treatment | Number of Collection Trays | | Number of Sample Trees | |
|---|---|---|---|---|---|
| | | 1936 | 1937 | 1936 | 1937 |
| 1 | Sprayed with concentrated mixture by autogiro | 50 | 50 | 37 | 15 |
| 2 | Dusted with autigiro | 20 | — | 18 | — |
| 3 | Sprayed with truck-drawn sprayer | 27 | 40 | 15 | 15 |
| 4 | Sprayed with colloidal mixture by autogiro | — | 20 | — | 15 |
| 5 | Untreated | 23 | 40 | 0 | 0 |

RESULTS.—Infestations in the different plots prior to treatment in 1936 are given as follows on the basis of an average dry weight of frass per tray in the check plot equal to 1: Plot 1, 1.1; plot 2, 1.3; and plot 3, 1.4. According to the data from the trays, cankerworm infestation was much lighter and more variable in 1937. An examination of cankerworm egg masses by C. H. Hoffmann and C. L. Griswold[3] in 1937 revealed a high mortality, which may partly account for the sudden drop in degree of infestation.

Since cankerworm infestation in the Morristown National Historical Park was variable in 1937, experimental plots were not always representative of conditions over entire areas. Therefore the results on larval feeding and mortality are given for 1936 only (Fig. 5). From general observations, however, it is believed that there was no significant difference between the results for the two years.

Although fig. 5, A and C, shows considerable control effected with the lead arsenate-oil impregnated dust, the diffi-

[3] Unpublished notes.

culties encountered in its application, such as drifting of the dust cloud and loss of dust from the foliage by wind, prevented this treatment from being entirely satisfactory.

It will be noted, figure 5, D, that there was more than 13 times as much feeding in the check plot as in the autogiro-sprayed plot and over 4 times as much feeding in the truck-sprayed plot as in the autogiro-sprayed plot. These figures are These data have been limited to the results of 1937, since the foliage samples taken in 1936 were so heavily fed upon it was found impossible to determine their area. It is believed, however, that the results of 1937 were very similar to those of 1936.

In the plot treated with the autogiro spray deposition was about the same as in that treated with the truck apparatus. Adherence, however, was considerably

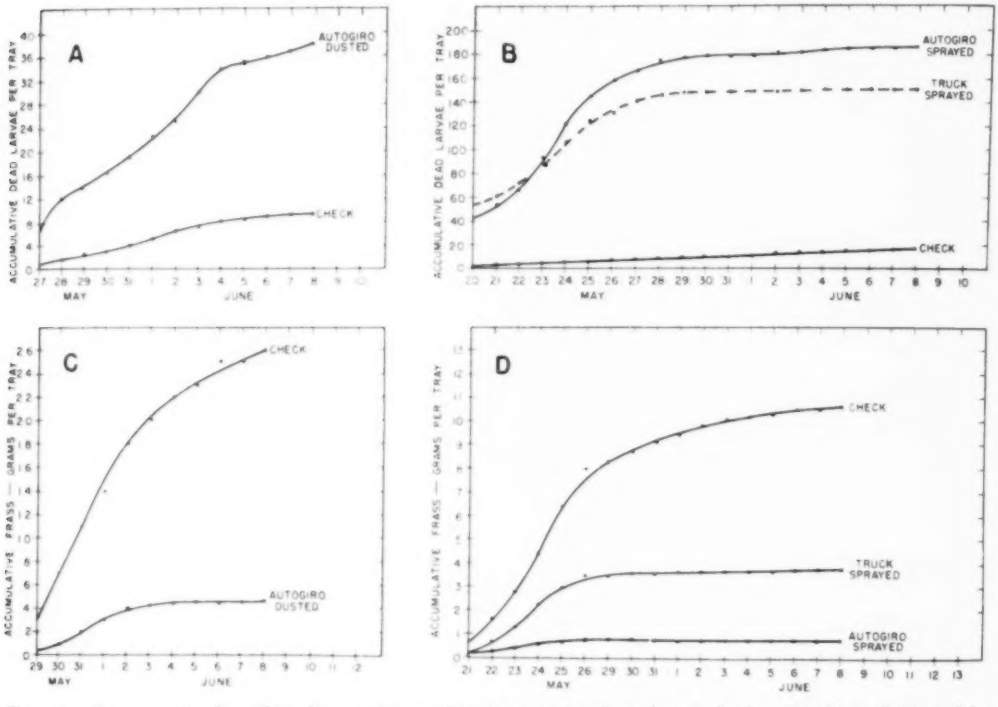


FIG. 5.—Comparative larval feeding and mortality in autogiro-dusted and check areas (A and C) and in autogiro-sprayed, truck-sprayed, and check areas (B and D).

significant when it is remembered that the frass recovery from these plots prior to treatment indicated a heavier infestation in both the truck-sprayed and autogiro-sprayed areas than in the check area. As shown in fig. 5, B, more dead larvae were recovered in the autogiro-sprayed plot than in either the check or truck-sprayed plots. This is probably accounted for by the better spray coverage on the tops of the trees sprayed by the autogiro.

In general these results were found to be in agreement with those of similar studies by Hamilton (1938).

Data on spray adherence and distribution are presented in tables 2 and 3.

better, probably because of better atomization and a greater proportion of fish oil to lead arsenate. The low deposit in the

**Table 2.—Adherence of insecticides to leaves sprayed with autogiro and truck-drawn sprayers, 1937.**

| TREATMENT | POUNDS OF LEAD ARSENATE APPLIED PER ACRE | AVERAGE MILLIGRAMS OF ARSENIC TRIOXIDE DEPOSITED PER SQUARE INCH | AVERAGE PERCENTAGE OF DEPOSIT LOST AFTER 3.18 INCHES OF RAINFALL |
|---|---|---|---|
| Autogiro-sprayed: | | | |
| Concentrated mixture | 22.0 | 0.054 ± .016 | 67 ± 6 |
| Colloidal mixture | 3.5 | .001 ± .0001 | 74 ± 8 |
| Truck-sprayed | 27.5 | .055 ± .009 | 83 ± 5 |

plot sprayed with colloidal lead arsenate is undoubtedly responsible in part for the low mortality obtained in this area.

**Table 3.—Distribution of insecticides on trees sprayed with autogiro and truck-drawn sprayers.**

| TREATMENT | PERCENTAGE OF TOTAL DEPOSIT ON FOLLOWING PARTS OF THE TREE CROWN | | |
|---|---|---|---|
| | Top | Middle | Base |
| Autogiro-sprayed (concentrated mixture) | 33 | 40 | 27 |
| Truck-sprayed | 16 | 48 | 36 |

The autogiro showed advantages over the truck sprayer in giving a better deposit on the top of the forest canopy, where much of the larval feeding occurs.

In regard to the comparative cost of the two types of spraying Francis (1936) states that autogiro spraying cost $7.23 per acre, whereas spraying with a 400-gallon power sprayer cost $14.33 per acre.

SUMMARY.—In 1936 and 1937 comparative tests on the control of the spring cankerworm *Paleacrita vernata* (Peck), and the fall cankerworm *Alsophila pometaria* (Harr.), were made in the National Historical Park at Morristown, N. J. These tests included the treatment of large woodland tracts with a concentrated spray mixture of lead arsenate, fish oil, paraffin oil, and water; a lead arsenate dust impregnated with paraffin oil; and a proprietary colloidal lead arsenate spray. All were applied with a specially equipped autogiro. In contrast to these tests certain areas were left untreated and other areas were treated with a standard lead arsenate, fish oil, and water spray applied with a high-pressure outfit drawn by a truck.

To determine the comparative feeding and kill of cankerworm larvae following the different treatments, samples were taken of the frass and dead larvae falling from trees in each observation plot. Yard-square cloth trays were placed at random and in sufficient number to cover 1 per cent of the ground area in each plot.

The comparative spray distribution and adherence in these plots was obtained by collecting and analyzing, before and after rain, leaf samples from the top, middle, and base of trees selected at random.

The results showed a marked reduction in the amount of feeding in the areas treated with the concentrated lead arsenate spray by means of the autogiro. This reduction was probably due to the improved coverage in the tops of the trees and to the improved adherence of the spray, apparently because of better atomization and an increased amount of fish oil per given quantity of lead arsenate. In all respects treatment by the autogiro compared favorably with that by the truck-drawn sprayer, and the cost per acre was less.

Although measurable control was obtained in the area dusted with an autogiro, some difficulty was encountered in regulating the drift of the dust.—5-19-41.

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## EASTERN PLANT BOARD TO MEET

The Eastern Plant Board will hold its annual meeting at Baltimore Maryland on November 12, just preceding the meetings of the Eastern Branch of the Association. The meetings will be held in the Lord Baltimore Hotel.

# An Infestation of the Pandora Moth, *Coloradia pandora* Blake, in Lodgepole Pine in Colorado

N. D. Wygant, *U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine*

An infestation of the pandora moth, *Coloradia pandora* Blake,[1] in pure stands of lodgepole pine, *Pinus contorta latifolia* Engelm., was discovered during August 1937 in the Arapaho National Forest in north-central Colorado. During 1938 and 1939 limited studies were made in that area on the life history and habits of the moth, as this was the first record of it reaching epidemic proportions in lodgepole pine and nothing was known about its biology in the Rocky Mountain Region.

Up to the time of the discovery of the Colorado infestation this insect was known chiefly as a pest of ponderosa pine, *Pinus ponderosa* Lawson, and Jeffrey pine, *P. jeffreyi* Greville and Balfour. Patterson (1929) states that in south-central Oregon, where thousands of acres of ponderosa pine were defoliated from 1918 to 1925, the insect reaches epidemic proportions at intervals of 20 to 30 years. In this area lodgepole pine was defoliated only when it occurred in stands with ponderosa pine. He also states that severe infestations have been recorded in only two localities, namely, south-central Oregon in ponderosa pine and south-central California in Jeffrey pine.

Nature of Injury.—There are three classes of injury which may result from feeding by the larvae. Defoliation may be so severe as to kill the trees directly, it may so weaken the trees that they are attacked and killed by barkbeetles, or it may result in decreased increment for a number of years before the trees recover. The larvae feed in all stadia indiscriminately on the needles, but the heaviest feeding occurs during the third, fourth, and fifth stadia, approximately from May 16 to July 15.

Distribution and Injury in the Southern Rocky Mountains.—*Coloradia pandora* was described by Blake (1863) from a female moth taken in the vicinity of Pikes Peak, Colo. Recent collection points known to the writer in the southern Rocky Mountains in addition to the Arapaho National Forest have been Rocky Ford, Estes Park, and Ward in Colorado, and near Jacobs Lake on the Kaibab National Forest in Arizona. The species apparently is widespread in this region, but up to the present was considered to be of little importance.

The infestation in 1939 covered approximately 100,000 acres on the western slope of the Continental Divide north of Hot Sulphur Springs, Granby, and Tabernash, Colo. Complete defoliation occurred in only 6 or 8 areas of 40 to 80 acres in size on the southern exposure on the East Fork of Troublesome Creek and Buffalo Creek drainages, 8,500 to 9,000 feet in elevation (Fig. 1, C). A survey in these areas during the latter part of August 1939 revealed that aprpoximately 4,000 trees had died as a result of the defoliation in 1937. Many heavily defoliated trees failed to put forth new needle growth in 1938 and 1939, but they had not yet died at the time of the survey. A less severe center occurred between Meadow Creek and Trail Creek on Strawberry Ridge north of Tabernash, Colo.

The confinement of heavy defoliation to southern aspects is apparently due either to temperature or soil conditions or to both. The southern slopes are warmer and the soil on these sites is composed of loose granite and is relatively free from duff and litter. The caterpillars seek these loose mineral soils for pupation. The northern slopes by contrast are colder and are generally covered with duff and litter.

Life History.—The biology of the pandora moth on lodgepole pine in Colorado is very similar to that found by Patterson (1929) working with the form on ponderosa pine in Oregon and California. The following is a brief resume of its biology in Colorado with mention of its variations from the West Coast form.

The average wing spread of 23 males was 75 mm. and of 37 females 81.5 mm. (Fig. 1, A and B), as compared with 85 and 96 mm., respectively, for the West Coast form.

The pandora moth normally has a 2-year life cycle, the adults emerging in the

[1] Determination by J. F. G. Clarke, Division of Insect Identification, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture, Washington, D. C.

even years. The peak of emergence occurs in the first half of July, but a few stragglers continue to appear throughout the summer. The moths emerge from the pupae in the soil and crawl up trees and other objects before their wings expand. The males are attracted to the females and often copulate before the wings of the females have expanded or dried. Females with dry unexpanded wings were of common occurrence, but this abnormality did not prevent mating and egg laying. The early flights of the females are of short distances, such as from the ground to a nearby tree or from branch to branch of the same tree. The males are better fliers than the newly emerged females, probably because the females are heavily laden with eggs. The abundance of adults during July 1938 is indicated by a count on a tree 8 inches in diameter and 25 feet high. On this tree there were 176 males and 126 females.

The blue neon lights in the towns of Granby and Hot Sulphur Springs, which were approximately 11 miles from known infestations, attracted numerous females and an occasional male during July and early August 1938. It is possible, however, that the adults came from unknown infestations nearer the towns. Each morning the dead moths were heaped beneath the lights by the bushels. The moths probably were migrating or in flight and were attracted to the lights when passing over the towns. Patterson (1929) in the studies with the pandora moth in southern Oregon found the insects to be strong fliers and strictly diurnal. He stated that the moths were not found active at night nor could they be attracted to lights displayed in the forest.

The males apparently are short lived and do not migrate from the infestation area. This is indicated by the fact that only an occasional male was attracted to the lights and only 15 per cent of 232 dead moths counted beneath 3 trees in the center of the infestation on August 3, 1938, were females. Observations indicate that the two sexes emerge from the pupae in about equal number.

The eggs develop in the pupae in the spring. The eggs, some of which may be laid the first day the moths emerge, are deposited singly or in clusters of 2 to 50, principally on branches, needles, and tree trunks (Fig. 1, D and E). The incubation period was not accurately determined but it appeared to be approximately 40 days, the period determined by Patterson. Very few of the eggs in the field failed to hatch.

The average number of eggs in 27 females collected on July 8, 1938, that had not oviposited was 153.1, with a range of from 109 to 187. The moths deposited most of their eggs before making long flights, as indicated by the fact that the average number of eggs in 50 females collected at a blue neon light in Granby, Colo., on August 2, 1938, was 19.7, with a range of from 0 to 97.

The eggs began to hatch during the first part of August and hatching continued throughout the summer. By August 26 approximately 50 per cent had hatched and by the last of September only a few remained unhatched on the north exposures. The larvae were gregarious during the first stadium, but during the second stadium seldom more than four could be

**Table 1.—Head measurements of *Coloradia pandora* larvae.**

| Instar | Number of Larvae | Average Width of Head, Inches | Range in Width, Inches |
|---|---|---|---|
| 1 | 50 | 0.0442 | 0.041–0.047 |
| 2 | 50 | .0667 | .063– .074 |
| 3 | 49 | .0870 | .082– .096 |
| 4 | 50 | .1214 | .112– .128 |
| 5 | 49 | .1637 | .152– .177 |

**Table 2.—Percentage of *Coloradia pandora* of each instar at various collection dates.**

| Collection Date | Number of Larvae | Per Cent of Indicated Instar | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 1938 | | | | | | |
| Aug. 30 | 500 | 100 | | | | |
| Sept. 20 | 307 | 88 | 12 | | | |
| Oct. 5 | 258 | 24 | 76 | | | |
| Nov. 10 | 179 | 3 | 93 | 4 | | |
| 1939 | | | | | | |
| May 19 | 568 | | 11 | 86 | 3 | |
| May 31 | 155 | | | 48 | 52 | |
| June 6 | 141 | | | 19 | 81 | |
| June 9 | 54 | | | 6 | 94 | |
| June 12 | 52 | | | | 90 | 10 |
| June 15 | 36 | | | | 75 | 25 |
| June 20 | 113 | | | | 50 | 50 |
| June 27 | 62 | | | | 6 | 94 |
| June 30 | 74 | | | | 4 | 96 |
| July 7 | 71 | | | | 1 | 99 |

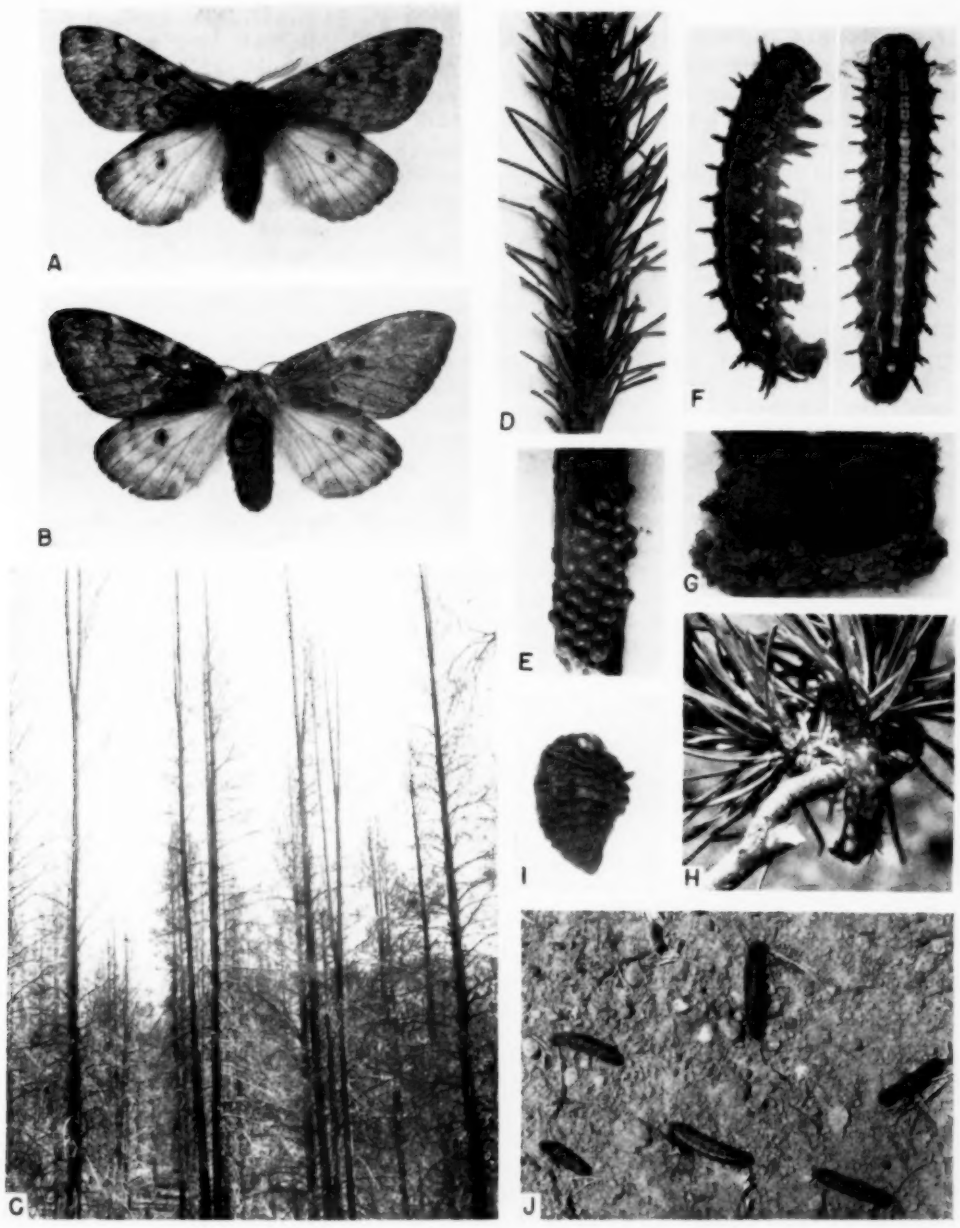


FIG. 1.—*Coloradia pandora* Blake: A, male moth (×0.9); B, female moth (×0.9); C, defoliated lodgepole pine; D, eggs on terminal shoot; E, egg cluster (×2); F, lateral and dorsal view of early fifth instar (×1.5); G, pupa in cell (×1); H, fifth instar killed by wilt disease; I, shriveled larva that failed to enter soil; J, mature larvae killed by soil-surface heat.

found in a group. The larvae overwintered on the branches at the base of the needles mostly in the second stadium with a few in the first and third stadia. They resumed feeding approximately the first of May 1939. Feeding was negligible each day until temperatures were above 60° F. By the last of June all had reached the fifth and last stadium (Fig. 1, F). The larvae began to enter the ground to pupate about July 7, 1938. By the last of July all had pupated except a few stragglers.

The various instars are distinguishable in the field by their relative sizes. Table 1

shows the width of the head capsules of the five instars and table 2 the relative proportions of the instars at various collection times during the larval stage.

Most of the larvae pupate in loose exposed mineral soil at a depth of 1 to 4 inches in cells sometimes lined with a thin layer of silk (Fig. 1, G). A few, however, enter the soil beneath litter and rocks. The pupae form within 24 hours after the larvae enter the soil. For unknown reasons very poor emergence was obtained from pupae collected and placed in rearing cages. The pupae ordinarily remain in the soil one winter only and the adults emerge the following July. A small proportion remained in the soil through two winters and the adults emerged during July 1939. This makes a 3-year life cycle instead of the usual 2-year cycle. On the East Fork of Troublesome Creek as many as 10 pupae per square foot were found during the fall of 1938 that ordinarily should have produced moths the preceding summer. On the Buffalo Creek drainage the highest number of holdovers in any area examined was 4 per square foot. The moths from these holdovers were common throughout the area in July 1939, but the numbers were negligible as compared with those which emerged in 1938.

NATURAL CONTROL FACTORS.—Extensive and severe defoliation was expected during the spring of 1939, but natural control factors reduced the population so that very little defoliation occurred.

*Winter Mortality:* Mortality of the larvae during the winter of 1938–39 reduced the population by at least 50 per cent. Since the larvae overwinter on the branches, they are subject to rigorous winter weather and to predators. According to inhabitants near the area it was one of the coldest winters in history. An unofficial temperature of minus 40° F. was supposedly registered in Hot Sulphur Springs, which is in a valley below and approximately 11 miles distant from the infestation.

*Wilt Disease:* A wilt disease was first noticed in the infestation on June 15, 1939, and subsequent to that date became more prevalent. The larvae affected turned orange brown and their body contents became liquid (Fig. 1, H). In this state the body wall ruptured very easily. The diseased larvae had a tendency to crawl out on the terminal branches before they died. On two trees artificially infested with 100 larvae each there was a mortality of 62 per cent on one and 58 per cent on the other between June 8 and July 14, 1939. It is believed that a comparable mortality resulted throughout the infestation.

Diseased larvae were sent to S. R. Dutky[1] who reported as follows:

"I have made microscopic examination of the remains of the dead pandora moth larvae. Although the larvae were too decomposed to permit any very definite conclusions to be drawn, it would seem, from the lack of bacteria or other organisms in the cadavers, that the larvae died of causes other than microbial infection. In all but one case not more than two bacterial cells per field were observed—a very small number considering the advanced state of decomposition.

"In all specimens a large number of small, refringent, sphaeroidal bodies were observed which appeared to be of crystalline nature. These were studied for their behavior toward fat stains, solubility in concentrated nitric acid, and appearance under polarized light, and staining reactions. The bodies did not stain with iodine, Sudan III, methylene blue, or picric acid, were insoluble in cold concentrated nitric acid, and were not doubly refracting (appeared dark under crossed polaroids). From their appearance and reactions, it appears likely that they might be 'polyhedral' bodies and it is possible that the wilt disease and death of the larvae might have been due to a polyhedral virus disease. Since no tissue cells or blood cells were found intact at the time of examination, it was not possible to determine the origin of these refringent bodies which were present in large numbers in all of the nine specimens sent. In order to determine whether these bodies originated in the nuclei and are associated with the exciting cause of the disease, it would be necessary to examine a number of larvae, preferably living larvae.

"It appears likely to me that the disease present among the larvae will prove to be a polyhedral virus disease, but in order to make a diagnosis of any certainty it will be necessary to have opportunity

[1] The writer is greatly indebted to S. R. Dutky, of the Moorestown, N. J., Laboratory of the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, for the examination and report on the diseased larvae.

to examine living larvae and to attempt infection tests."

*Heat and Drought:* During July 1939 heat and drought had very deleterious effects on the larvae trying to enter the soil to pupate. The July of 1939 was one of the driest and hottest in the history of the area. The larvae usually seek loose, exposed, mineral soils in which to pupate, and such spots usually receive the direct rays of the sun. Although air temperatures, as measured in a Weather Bureau type of instrument shelter, were never above 90° F., soil-surface temperatures at times became very high. At the elevation of the infestation, approximately 9,000 feet, the sun is intense. On July 11 at 10:30 A.M. the soil-surface temperature beside a larva that had just died was 138° and one-half inch below the surface 135°. On the same afternoon at 2:30 P.M., just after a larva had successfully entered the soil, the temperature at the surface was 102° and the temperature just below the surface 100°. On July 13 at 10:45 A.M. the temperature at the surface where several larvae had died was 142° and one-half inch below the surface was 124°. When exposed to such high temperatures, the larvae become very active for a few minutes and then become inactive and die (Fig. 1, J). The mortality at this stage may not all be caused from heat alone. Sometimes the larvae got half to nearly all of their bodies buried and hit an obstruction. They would then seek another spot and start digging again. A number of larvae were observed which apparently died from exhaustion.

The number of dead larvae on the surface and the number of live pupae in the soil were counted on eight sample plots, each of 36 square feet of soil surface, on July 14 and 15, 1939. The samples were taken in areas where the mineral soil was exposed and of the type preferred for pupation. The lowest mortality in the samples was 34 per cent and the highest 55 per cent (Table 3). The average mortality was 43 per cent.

In August 1937 the ground was covered with dead larvae at many of the spots selected for pupation. At that time their death was attributed to the action of heat before they could dig into the soil. The larvae at that time were greatly shortened or ball shaped and appeared to have reached the prepupal stage, and probably died because they were unable to enter the soil (Fig. 1, I). The dead larvae on the surface during July 1939 were dried and flattened and not ball shaped.

*Predators:* During the fall of 1937 it was evident that squirrels and bears were destroying many of the pupae. The bears had overturned many flat stones and the squirrels had dug small cone-shaped holes in the ground in search of pupae. Animal feces composed almost entirely of pandora moth eggs were found in July 1938. No birds have been observed feeding on the caterpillars.

**Table 3.—Mortality of *Coloradia pandora* larvae entering the soil.**

| Sample No.[1] | Number of Live Pupae | Number of Dead Larvae | Per Cent Mortality |
|---|---|---|---|
| 1 | 9 | 7 | 44 |
| 2 | 10 | 12 | 55 |
| 3 | 25 | 28 | 53 |
| 4 | 72 | 37 | 34 |
| 5 | 33 | 27 | 45 |
| 6 | 46 | 32 | 41 |
| 7 | 41 | 39 | 49 |
| 8 | 19 | 18 | 49 |
| Total | 255 | 200 | 43 |

[1] Samples made on July 14 and 15, 1939, each 36 square feet.

*Parasites:* The pandora moth in this infestation has been unusually free from parasitization. Several specimens of *Apanteles* sp. were reared, and these were from a single larva. Patterson (1929) reared two species of egg parasites and two species of larval parasites from the pandora moth in southern Oregon.

SUMMARY.—An infestation of the pandora moth in lodgepole pine on the Arapaho National Forest in north-central Colorado was discovered in August 1937. This is the first known record of the insect's building up to epidemic proportions in pure lodgepole pine stands.

In 1938 and 1939 general observations and limited studies were made in the area. The insect has, as a rule, a 2-year life cycle, but a few individuals remained in the pupal stage an extra year, making it a 3-year life cycle. The main emergence of the moths occurs in July of even years. The moths mate and lay eggs very soon after emergence. The eggs hatch in about 40 days. The larvae go through five stadia. They pass the first winter in the

second stadium on the twigs and reach maturity the following July. They then pupate in cells in loose mineral soil, at a depth of 1 to 4 inches, where they pass the second winter. The eggs form in the pupae in the spring and the moths emerge in July.

The epidemic had the aspects of becoming very serious until 1939, when natural control factors greatly reduced the population. There was at least a 50 per cent mortality of the larvae during the winter of 1938–39, probably from low winter temperatures. A wilt disease killed approximately 60 per cent of the remaining larvae in the fourth and fifth stadia in June and July 1939. The affected larvae turned orange brown and their body contents became fluid. At the time the larvae were entering the soil, July 1939, approximately 43 per cent of the remaining population were killed by the effects of heat and drought. Only one species of parasite, *Apanteles* sp., was reared. Bears and squirrels fed upon the pupae.—7-23-41.

## LITERATURE CITED

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# Cold Hardiness of Two Species of Bark Beetles in California Forests

J. S. YUILL, *U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine*[1]

During past years reports of high mortality in bark beetle populations following periods of extreme cold have come from various parts of the country. Such reduction in the numbers of overwintering broods, of course, has a highly important bearing on the planning and directing of control operations. Consequently, when it was found that the abnormally low temperatures during the winter of 1932–33 had adversely affected overwintering broods of the western pine beetle, *Dendroctonus brevicomis* Lec., from central California to Canada and into Montana, the greater portion of its natural range, Keen and Furniss (1937) made an extensive study in the pine forests of eastern Oregon to determine the conditions under which winter killing of this species takes place. They reported that extensive mortality can be expected to result from the periods of extremely cold winter weather that occur at irregular intervals of approximately 10 years, but that the amount of killing varies considerably with local temperature conditions in different areas, bark thickness and moisture content of the infested trees, and other factors.

This paper reports the results of a current study carried on in California to determine the direct effect of low temperatures on bark beetles under controlled laboratory conditions. This investigation is a continuation of work initiated by Miller (1931) and includes as subjects the western pine beetle and the mountain pine beetle, *Dendroctonus monticolae* Hopk., the two most important insect enemies of standing timber in the California region. The experiments were carried on over a period of 4 years, during which some 60 tests were made and a total of approximately 25,000 larvae were used. For the sake of brevity, results of only a few representative tests have been included in this paper. Investigation was limited to the fourth (last) instar of both species, for it is principally in that stage that the winter is passed. The work was directed toward answering the following questions:

(1) What temperatures are fatal to the larvae of these two species, and are the same temperatures fatal at all times of the year?

(2) How long must a period of low temperature exist to cause mortality?

(3) Are the larvae of the same species more cold hardy when developing in one host than in another?

[1] This paper includes data from office reports of the Bureau of Entomology and Plant Quarantine by J. M. Miller and G. R. Struble.

The last question arose only in connection with the mountain pine beetle, for the western pine beetle is found only in one host, ponderosa pine, in the commercial timber belt.

MATERIALS AND METHODS.—Western pine beetle larvae were obtained from naturally infested trees in the forest. Mountain pine beetle larvae, on the other hand, were obtained by inducing attacks of caged adults on small, freshly cut logs of sugar pine, *Pinus lambertiana* Dougl., ponderosa pine, *P. ponderosa* Laws., and lodgepole pine, *P. contorta* Loud.

In tests to determine the effect of the host on cold hardiness each lot of host material was subjected to the same climatic conditions during development of the larvae.

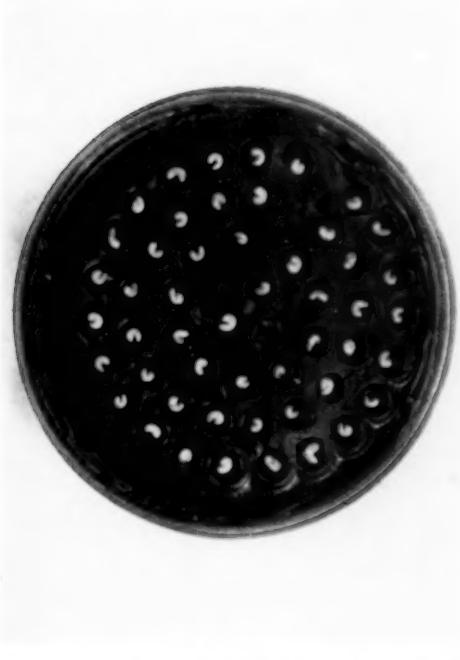

FIG. 1.—Paraffin cell holder used in testing cold hardiness of bark beetle larvae.

Since the insulating effect and moisture content of the bark presented variables that could not be evaluated, larvae were removed from the host material and placed in individual open cells moulded in a layer of paraffin in the bottom of a petri dish (Fig. 1). Lots of 50 to 100 larvae were used for each temperature point, or period of exposure, whenever possible, although in a few cases smaller numbers were employed. Exploratory tests demonstrated that, for purposes of comparison, an exposure of 2 hours plus an allowance of 15 minutes for cooling of the petri dish gave a satisfactory measure of cold hardiness. This period was therefore adopted as standard in all tests except those involving the effect of various periods of time at different lethal temperatures. All exposures were made in a well-type mechanical refrigerator having an operating range of 25° to −25° F.

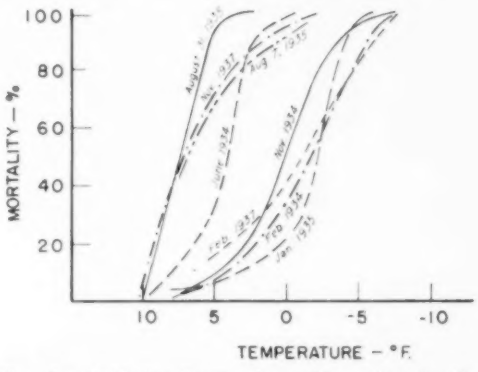


FIG. 2.—Cold hardiness of western pine beetle larvae, showing the distinct summer and winter phases. The dates given on each curve indicate when the test was made.

TESTS WITH WESTERN PINE BEETLE LARVAE.—The temperatures fatal to larvae of *Dendroctonus brevicomis* were found invariably to lie within certain fixed limits. These limits, however, were not found to be the same throughout the year, but fell into two distinct phases, which, for convenience, have been designated as the summer and winter conditions. Under the summer condition the critical temperature range was 10° to −2.5° F. and under the winter condition 5° to −7.5° (Fig. 2).

In areas where fatal low temperatures occur there are two generations, and sometimes a partial third generation, of this species each year. In the first, or early summer, generation the summer condition prevails without change. In the second and third, or overwintering, generations the larvae are in the summer condition during warm weather; the least hardy individuals are killed by temperatures of approximately 10° F. and the most hardy die around zero to −2.5°. This critical range remains at the same

level until the beginning of cool weather late in October or early in November, when within 6 weeks or less cold hardiness increases to the winter condition. Once the transition from the summer to the winter condition is made, the degree of cold hardiness again stands at a constant level until the larvae pupate in the spring. Variations may occur at intermediate points, but the upper and lower limits of the critical range evidently remain fixed. It also appears that the level of resistance developed each winter is always the same whether the season is mild or severe.

**Table 1.—Effect of conditioning temperatures on cold hardiness of western pine beetle larvae.**

| Collection Date | Conditioning Temperature | Conditioning Period | Critical Range |
|---|---|---|---|
| | *Degrees F.* | *Days* | *Degrees F.* |
| Dec. 1934 | Check | 0 | 5 to −7.5 |
| | 70 | 7 | 7.5 to −5 |
| | 36 | 7 | 5 to −5 |
| Mar. 1936 | Check | 0 | 5 to −5 |
| | 36 | 18 | 5 to −5 |
| Nov. 1937 | Check | 0 | 10 to −2.5 |
| | 36 | 35 | 2.5 to −7.5 |

Several attempts were made to change the cold hardiness of both overwintering generations by subjecting them, in the bark, to several combinations of temperatures above and below the developmental threshold. Sample lots of larvae, to be used as checks, were not subjected to conditioning temperatures, but were tested for cold hardiness at the beginning of each experiment as they came in from the field.

As shown in table 1, appreciable change in cold hardiness could be induced only in the case of larvae collected in November, which had just begun the transition from the summer to the winter condition. The slight decrease in cold hardiness shown for the larvae collected in December was probably due to inherent variation in the resistance of individual larvae and to experimental error. Apparently factors other than temperature alone are required to initiate a change in cold hardiness in this species, and, as the larvae of the mountain pine beetle were discovered to be much more responsive to changes in environmental temperatures, all further experiments on conditioning were carried on with that species.

As pointed out by Payne (1927), there are two factors to be considered in studying the lethal effects of low temperatures, as follows: (1) The intensity factor, or temperature points, to which the organism is subjected and (2) the time factor, or length of the exposure, at a given point. To test the role of the second factor, overwintering larvae of the western pine beetle were held for various periods at points within and just above the critical range. The results of these tests are shown in table 2 and figure 3.

The exposure period required for mortality was not the same at all lethal temperatures tested. At +7.5° F., a point just above the critical range, mortality was little higher for exposed larvae than for unexposed larvae, even when the individuals were held 4 days. When larvae were subjected to a temperature of zero, within the upper critical range, however, the mortality definitely increased with increasing exposure time. The death rate increased rapidly up to 2 hours and then continued to rise more gradually up to the seventh or eighth day, after which it fluctuated between 75 and 90 per cent until the experiment was terminated on the eighteenth day. In addition to increasing the mortality, prolonged exposures at 0 degrees had a pronounced inhibitory effect on the subsequent development of the

**Table 2.—Effect on western pine beetle larvae of various periods of exposure at temperature points within and above the critical range.**[1]

| +7.5 Degrees F. | | Zero Degrees F. | | −7.5 Degrees F. | |
|---|---|---|---|---|---|
| Exposure | Mortality | Exposure | Mortality | Exposure | Mortality |
| *Hours* | *Per Cent* | *Hours* | *Per Cent* | *Minutes* | *Per Cent* |
| Check | 2 | Check | 0 | Check | 0 |
| 1 | 4 | 1 | 6 | 20 | 30 |
| 4 | 6 | 2 | 26 | 30 | 58 |
| 8 | 8 | 3 | 30 | 40 | 88 |
| 16 | 6 | 5 | 18 | 50 | 92 |
| 24 | 10 | 8 | 23 | *Hours* | |
| *Days* | | 16 | 40 | 1 | 98 |
| 2 | 6 | 36 | 36 | 2 | 100 |
| 3 | 12 | *Days* | | | |
| 4 | 16 | 2 | 41 | | |
| | | 3 | 9 | | |
| | | 4 | 49 | | |
| | | 5 | 68 | | |
| | | 6 | 83 | | |
| | | 7 | 82 | | |
| | | 8 | 83 | | |
| | | 9 | 78 | | |
| | | 10 | 88 | | |
| | | 12 | 90 | | |
| | | 14 | 86 | | |
| | | 16 | 84 | | |
| | | 18 | 40 | | |

[1] Checks held at room temperature over the period of the experiment, or until the larvae entered the pupal stage.

survivors, for none of the larvae that were alive after an exposure of 6 days or more were able to reach the pupal stage when returned to developmental temperatures. In the lower portion of the critical range the exposure period again assumed a minor role. At −7.5° practically all individuals were killed by exposures of only 1 or 2 hours. In general, then, it seems that for western pine beetle larvae the length of time they are subjected to lethal temperatures influences mortality only at points in the upper critical range and at all other points the intensity of the cold rather than the period of the exposure is the governing factor.

RESULTS OF TESTS WITH MOUNTAIN PINE BEETLE LARVAE.—The temperatures fatal to larvae of *Dendroctonus monticolae* do not fall within fixed limits, but cold hardiness does exhibit the summer and winter conditions (Fig. 4). In larvae taken from sugar pine, for example, the critical range during the summer months was +15 to +7.5° F., and by January it had dropped from 7.5 to −10°. The spread between the upper and lower limits also changes with the season. During the summer there was a difference of only 7.5° between the points at which the least hardy and most hardy individuals were killed, but by midwinter the difference increased to approximately 17.5°. This behavior is

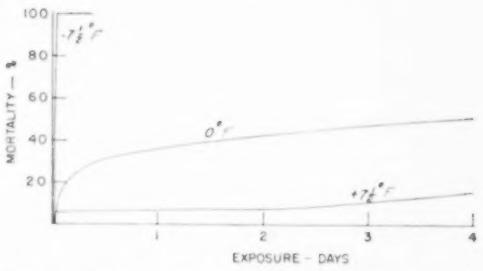


FIG. 3.—Effect on overwintering western pine beetle larvae of prolonged exposures at various lethal temperatures.

in contrast to that of *D. brevicomis* larvae, which show a critical range of about 12.5° throughout the year.

The difference in resistance between larvae collected from sugar pine in August 1935 and these collected in October (Fig. 4) is probably due to inherent variations in individuals. Such variations are most pronounced in larvae in the summer condition, particularly those from this host.

The transition from the summer to the

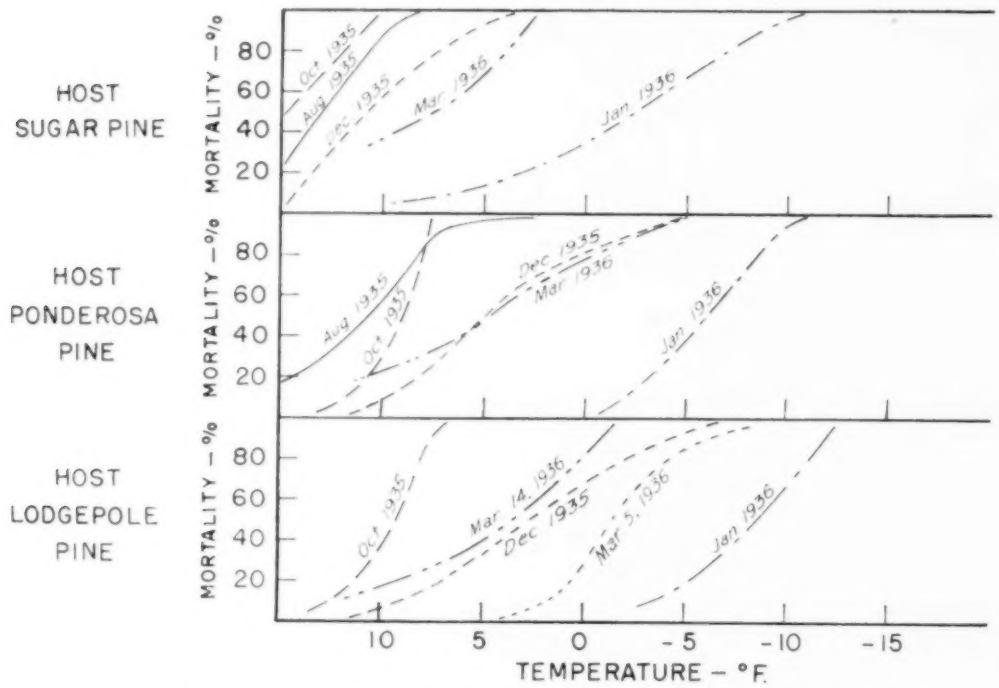


FIG. 4.—Cold hardiness of mountain pine beetle larvae, showing summer and winter phases in different hosts.

winter condition is also different in this species from that in western pine beetle larvae. Instead of taking place within a few weeks, the increase in cold hardiness comes as a slow progression beginning in October or November and reaching a peak in January or February (Fig. 4). This peak does not come to the same fixed level each year, but apparently changes

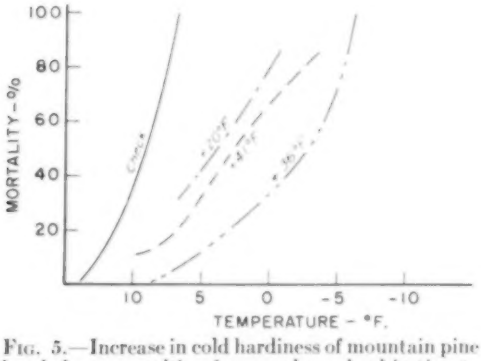


FIG. 5.—Increase in cold hardiness of mountain pine beetle larvae resulting from prolonged subjection to subdevelopmental temperatures.

with the severity of the climate. For example, larvae in lodgepole pine from an area in the central Sierra region of California, where the minimum winter temperature did not go below 8° F., developed a critical range of 5 to −12.5° whereas larvae in the same host from the Ft. Klamath region of Oregon, where winter temperatures of −15° are common, had a critical range of −5 to −20°, even after having been transported 400 miles in the Berkeley laboratory for testing. As the days become warmer in the spring, March and April, cold hardiness slowly changes in the opposite direction. This change continues until the larvae go into the pupal stage in April and May.

Two experiments to determine the cause of changes in cold hardiness were carried out with larvae of the mountain pine beetle. In the first the object was to lower the critical range. Small lodgepole pine logs containing larvae in the summer condition were divided into four lots, three of which were held at 20, 36, and 41° F. for 5 weeks. The fourth lot was not subjected to conditioning temperatures, the larvae in them being tested at the beginning of the experiment. The results are shown in figure 5.

When the conditioned larvae were tested it was found that the group held at 36° F. had increased their cold hardiness to a state midway between the summer and the winter conditions, those held at 41° were slightly less hardy, and those subjected to 20° were the least hardy of the three. It would be logical to expect that the lower the conditioning temperature the greater would be the increase in cold hardiness, which was true for the 41 and 36° groups, but did not hold for the larvae held at 20°. The reason for this irregular behavior is not clear, but it may have been that the sudden change from a developmental temperature to one below the freezing point of water inhibited alteration in water balance or some other essential physiological change. Similar tests with larvae taken from sugar pine and ponderosa pine gave the same results.

In the second experiment the object was to reduce the critical range. Small logs of lodgepole pine containing larvae in the midwinter condition were held at a developmental temperature of 75° F. for a period of 2 weeks and then tested. One lot of the material was tested without being conditioned. The results are given in figure 6.

The cold hardiness of the conditioned larvae underwent a pronounced change, reverting to a state similar to that found

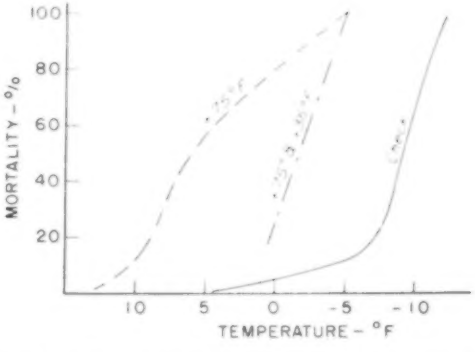


FIG. 6.—Reduction in cold hardiness of mountain pine beetle larvae resulting from exposure to a developmental temperature of 75° and redevelopment of cold hardiness by subjection to a temperature of 36° following the period at 75°.

to exist during the spring months. One log of conditioned material not tested was placed at 36° F. for an additional 23 days. By the end of the second conditioning period the larvae had begun to regain cold hardiness lost during the time they were held at the developmental point. This

ability of the mountain pine beetle larvae to increase or decrease markedly their cold hardiness at any time of the year is different from the fixed pattern of behavior found in the larvae of the western pine beetle, and, judging by the results of the tests on both field- and laboratory-conditioned material the changes are governed principally by environmental temperatures.

Only one test was carried out with mountain pine beetle larvae to determine the time that lethal temperatures must exist to cause mortality, and, as the reaction was similar to that of the western pine beetle larvae, no further work was done along this line.

INFLUENCE OF HOST ON COLD HARDINESS.—The experiments conducted to determine the influence of the host species on cold hardiness of mountain pine beetle larvae were carried on as part of the series of tests to study the seasonal cycle. The results are given in table 3 and figure 4.

In every case larvae from lodgepole and ponderosa pines were definitely more resistant than those from sugar pine. The difference in resistance was greatest in the fall and least in midwinter and midsummer. Larvae from lodgepole pine are perhaps slightly more resistant than those from ponderosa pine, but the difference is so small that it can not be considered significant.

No work has been done to determine the cause of differences in cold hardiness, but some observations of a general nature have been made. The insulating properties of the bark are not responsible, for in lodgepole pine the bark thickness rarely exceeds one-fourth inch, whereas in ponderosa pine and sugar pine the bark may be 3 inches or more in thickness. It is possible that nutritional factors may be involved, for the broods developing in lodgepole and ponderosa pines are often larger, faster growing, and generally more vigorous in appearance than those in sugar pine.

COLD HARDINESS AND WINTER MORTALITY.—Since the ultimate purpose of a study of this kind is to gain a better knowledge of the effect of low temperatures on bark beetle populations in the forests, an attempt will be made to interpret these findings in terms of conditions in the field.

The results indicate that mortality in overwintering broods of the western pine beetle might be expected either as a result of a prolonged cold snap of moderate intensity in the fall before the larvae have made the transition to the winter condition or following a period of unusual intensity in midwinter. Actually, the sudden cold spells in the fall are relatively unimportant. Occasionally some mortality does occur, but because of the lag of subcortical temperatures behind air temperatures (Beal 1934) the larvae are rarely, if ever, subjected to points lower than the upper critical range. The laboratory tests have demonstrated that high mortality rates at these points can be induced only by prolonged exposures, and unfortunately diurnal fluctuations in temperature prevent the time factor from becoming operative. It is the severe midwinter cold waves which occur at intervals of several years that cause widespread killing of western pine beetle broods. At such times the air temperatures fall sufficiently to bring subcortical temperatures to points within or below the lower critical range of the overwintering larvae. Such periods of extreme cold are of added effectiveness in that, as shown by the tests, short exposures, once the surrounding bark is cooled to temperatures in the lower critical range, will cause as high mortality as will longer ones. Since cold hardiness in western pine beetle larvae does not decrease during the spring months, periods of unseasonable cold at that time would have no effect on the overwintering broods.

Because of the insulation afforded by the bark, air temperatures of −15 to −20° F. and lower are required to cause any appreciable mortality in these over-

**Table 3.—Cold hardiness of mountain pine beetle larvae developing in different host species.**

| Collection Date | Sugar Pine Critical Range | Ponderosa Pine Critical Range | Lodgepole Pine Critical Range |
|---|---|---|---|
| | *Degrees F.* | *Degrees F.* | *Degrees F.* |
| 1935 | | | |
| August | above 15 to 7.5 | 15 to 5 | — |
| October | above 15 to 10 | 12.5 to 7.5 | 12.5 to 7.5 |
| December | 15 to 2.5 | 10 to −5 | 10 to −7.5 |
| 1936 | | | |
| January | 10 to −10 | 0 to −12.5 | 0 to −12.5 |
| March | above 10 to 2.5 | 10 to −5 | 5 to −7.5 |
| July | 15 to 7.5 | 15 to 2.5 | above 15 to 5 |
| October | 15 to 12.5 | 12.5 to 5 | 12.5 to 5 |
| December | above 15 to 7.5 | 10 to −2.5 | 10 to −2.5 |

wintering broods under forest conditions. In California such winter minima have occurred in the east-side ponderosa pine stands in the northeastern part of the State, and have killed as high as 65 per cent of the overwintering broods (Miller 1933). The higher minima, which occur in the west-side ponderosa pine belt of the central Sierras, do occasionally cause some winter mortality, but it rarely, if ever, exceeds 20 per cent of the population. No winter killing of the western pine beetle has been reported in southern California or the northern coastal areas.

The ability of the overwintering larvae of the mountain pine beetle to develop resistance to meet a wide range of temperature conditions explains the absence of winter mortality in this species. Temperatures in the coldest forested areas of California, even in the most severe winters, do not fall below the limits to which these larvae can accustom themselves, and whereas the larvae in sugar pine are much less cold hardy than those in lodgepole pine, the winter temperatures of the sugar pine belt are always much less rigorous than those prevailing in the lodgepole pine stands.

WINTER MORTALITY AND CONTROL OPERATIONS.—The beneficial effects of winter mortality of western pine beetle broods in the commercial pine forests depends on (1) the proportion of the population that has been destroyed and (2) the trend of the infestation, increasing or declining. If only a small part of the brood are killed, the reduction in numbers will be so slight as to be of no consideration in the formulation of control plans. If, on the other hand, the mortality is high, 50 per cent or more, the decrease in timber loss may be extensive or temporary depending on the population trend.

In an epidemic infestation that has definitely passed the peak and begun to decline, high winter mortality would make control work inadvisable, since the population would soon return to an endemic state through the work of natural agencies alone. In an epidemic that is definitely aggressive, however, the reduction of broods by low temperatures is only temporary, the population returning to the previous level in 1 or 2 years. This is shown by the timber loss on the Modoc National Forest during the period 1931–34, as follows:

| Year | Average loss per acre, board feet |
|---|---|
| 1930 | 96 |
| 1931 | 246 |
| 1932 | 321 |
| 1933 | 207 |
| 1934 | 363 |

Although an aggressive epidemic was in progress during these years, a sharp reduction in insect numbers resulted from low temperatures during the winter of 1932–33, which in turn decreased the timber loss the following season. However, conditions still were favorable for an increase in the beetle population and by the next year the loss exceeded that sustained before the winter killing.

Since the overwintering larvae of the mountain pine beetle have the ability to develop a degree of cold hardiness sufficient to survive any winter temperatures likely to occur in the California region, winter mortality will probably never be a consideration in planning for control of this insect.

SUMMARY.—This paper summarizes the results of a 4-year study on the effect of low temperatures on the larvae of two of the principal timber-killing bark beetles of the California region, the western pine beetle, *Dendroctonus brevicomis* Lec., and the mountain pine beetle, *D. monticolae* Hopk. In this work 60 tests were carried out, in which over 25,000 larvae were subjected to various temperature conditions.

In California overwintering larvae of the western pine beetle are killed by a temperature range of 5 to −7.5° F. and those of the mountain pine beetle by a range of 15 to −12.5°.

Prolonged exposures increase mortality in the upper critical range, but as the temperature is reduced the intensity of the cold (temperature point) becomes the governing factor rather than the length of the exposure.

Cold hardiness varies with the season. With larvae of the western pine beetle the difference between the summer state and the winter state is relatively small, and the change from the former to the latter takes place in a comparatively short time. With larvae of the mountain pine beetle the resistance gradually increases as the season becomes cooler and covers a wider range than does that of the other species.

Larvae of the mountain pine beetle show a pronounced difference in cold hardiness when developing in different hosts. Those from lodgepole and ponderosa are more resistant than those from sugar pine.

In the northeastern portion of the State cold waves of such intensity occasionally occur that overwintering broods of the western pine beetle are reduced by as much as 65 per cent. In other areas the winter mortality is never extensive. Mountain pine beetle larvae are rarely, if ever, killed by winter temperatures in the California region.

The consideration of winter mortality in planning control operations is discussed.—7-3-41.

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# A Preliminary Report on Control of the Western Twelve-Spotted Cucumber Beetle in Orchards

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For a number of years the western twelve-spotted cucumber beetle, *Diabrotica 11-punctata* (Man.),[1] has been known to be a serious pest of deciduous fruits in several localities in California. Not only has much damage been done due to direct feeding, but large losses have resulted through the spreading of brown rot. In the Brentwood area of California the losses were so great in 1938 that the farmers in that region asked that the problem be investigated. Work was started late in the harvest season and, although of a limited nature, information was obtained which indicated that it should be possible to control the insect with certain contact insecticides applied as dusts. In 1939 a serious infestation of the pest failed to develop and for that reason it was impossible to carry on any extensive control experiments. However, population trends were followed and observations were made on the reaction of the beetles to dusting in relation to weather conditions. Large populations were encountered in 1940 and this report deals principally with the results of that season's work.

POPULATION TRENDS AND DISTRIBUTION OF DIABROTICA IN ORCHARDS ABOUT BRENTWOOD.—The *Diabrotica* population in 1940 was much larger than that encountered in 1939. The average population per tree in orchards reached as high as 776 beetles, whereas in 1939 the greatest number collected on the average in any orchard was 16. Although the population was large in some orchards, there were others where relatively few beetles could be found. The population trends in three orchards are shown graphically in figure 1. These show that there was a wide variation in the populations observed in the three different orchards. The variation noted was probably more closely connected with the orchard location than with the kind of fruit or condition of the orchard. In all three cases the orchards were young and the foliage dense, a condition very favorable to *Diabrotica*. The highest population was found in the peach orchard which was isolated just outside the periphery of the main orchard area southwest of Brentwood. The next highest population was found in the nectarine

[1] The western twelve-spotted cucumber beetle has generally been known under the name of *Diabrotica soror* Le Conte (1865, On the species of *Galeruca* and allied genera inhabiting North America. Proc. Acad. Nat. Sci. Phila., 1865: 204–22). However, E. G. Linsley has pointed out to the writers that an older name is apparently available in *Diabrotica 11-punctata* Mannerheim (1843, Beitrag zur Kaeferfauna der Aleutischen Inseln, der Insel Sitkha und New-Californiens. Bull. Soc. Imp. Nat. Moscou, 16: 175–314). Mannerheim treated the species as a variety (var. b.) of the twelve-spotted cucumber beetle, *Diabrotica 12-punctata* (Fab.). He described it recognizably, recorded it from California and noted that it was the *Galeruca 11-punctata* of Eschscholtz (*in litteris*). Apparently, however, the name had not been previously validated by Eschscholtz and should therefore be attributed to Mannerheim.

orchard southwest of Brentwood on the periphery, but not isolated from the orchard area. The smallest population shown was in a nectarine orchard just northwest of Brentwood and well in from the periphery of the fruit-growing area. The region of heaviest infestation encompassed the fringe of orchards from south-

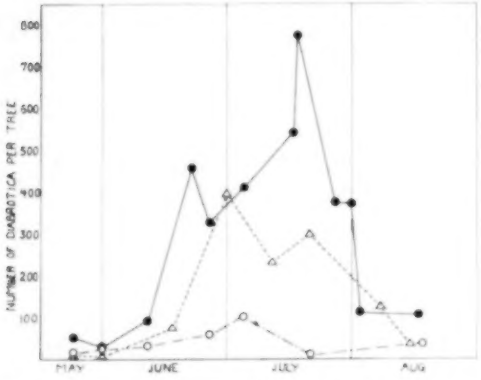


FIG. 1.—Diabrotica population trends in three orchards at Brentwood, 1940.
● Isolated peach orchard on periphery of orchard area.
△ Nectarine orchard on periphery of orchard area.
○ Nectarine orchard well in from periphery of orchard area.

east to northwest of Brentwood. Inward from this area the infestation in general became less. This is clearly shown in figure 2 where the maximum populations encountered in different orchards are presented graphically.

From our observations it appears that infestations within an orchard do not arise from a build-up of a beetle population therein, but from migrations into the orchard. It is believed that the beetles move into irrigated areas as the uncultivated and unirrigated regions begin to dry up. This, beyond a doubt, accounts for some of the migrations into the orchards but because of the large populations found in orchards long after uncultivated areas dry up, it would seem that some of the beetles arise from other sources. The largest populations observed so far however have been found consistently in the fringe of orchards that adjoin uncultivated areas.

There are apparently several factors that stimulate *Diabrotica* to migrate. The drying up of cultivated and uncultivated regions is certainly an important one. Temperature may be equally important. There is little doubt but that high temperatures stimulate the beetles to seek cooler locations. This may cause local or possibly extensive migrations from a distance. Because the beetles try to escape the heat they tend to seek the trees that have the most dense foliage. In such trees there is also a movement towards the shady side as the temperature rises during the hottest part of the day. Because denseness of foliage is an important factor, peach and nectarine trees generally offer a more suitable environment for the beetles than do apricot trees. This is particularly true of the younger peach and nectarine trees. In the case of apricot trees the beetle population always falls off abruptly as soon as the crop is harvested. While the ripe or nearly ripe fruit is still on the trees the beetles find conditions most favorable for their existence: protection from the heat could be found about the fruit and foliage. Ripe fruit is preferred as food. It

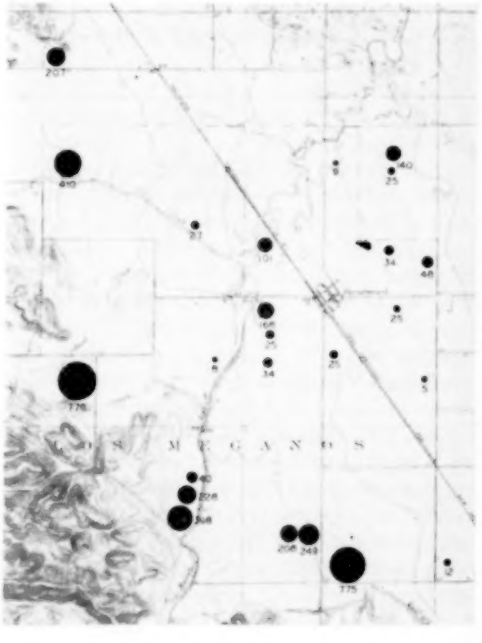


FIG. 2.—Maximum *Diabrotica* population found per tree in different orchards in the Brentwood Area, 1940.

furnishes ample moisture and the feeding punctures can be utilized for protection. Following harvest, apricot trees in their partially wilted and open condition no longer offer a suitable environment and the beetles leave such trees. Nectarine and peach trees on the other hand may furnish

a suitable environment for *Diabrotica* before, during, and after harvest. Before the fruit is ripe and after harvest very large populations may be encountered.

INJURY.—Green fruit is in very little danger of being injured by *Diabrotica*. However, if placed in a cage with no other food they will feed on it. Because green fruit is relatively free from attack, large *Diabrotica* populations may be present in an orchard without any great amount of fruit injury occurring. Once the fruit starts to color it is in danger of being attacked and as ripening progresses this danger increases. In the case of nectarines where fruit was harvested "mature green" for eastern shipment little or no fruit was damaged despite the fact that the *Diabrotica* population in some orchards exceeded 300 to the tree. As long as fruit is green the insects apparently prefer to feed on the foliage and large populations in the orchard are of no immediate concern. Fruit is attacked as it ripens and feeding may proceed to a point where fruits are rendered worthless. It is possible that once a fruit is injured it serves, in a measure, to protect other uninjured fruit, since the beetles probably prefer injured to sound fruit. Because of the attractive nature of ripe fruit, a relatively small *Diabrotica* population may do considerable damage and if fruit is selling at a high price, control measures may be desirable. Since fruits are not attacked until they start to color, the period over which *Diabrotica* must be controlled will seldom exceed 10 days to 2 weeks.

The injury caused by the beetles can be divided into primary and secondary damage. Primary injury may be considered as occurring when fruits are attacked by *Diabrotica* only, while secondary injury occurs when the beetles feed on fruit which has been damaged previously by some other agency. Primary damage ranges from extremely small feeding punctures to many large and deep-feeding punctures completely destroying the fruit. Where fruit is intended for the fresh market, the smallest puncture renders it worthless because of the danger of brown rot developing. The break in the skin is a portal of entry for the brown rot organism and not only may the injured fruit be destroyed but, in transit the surrounding fruits may also be affected. In the field *Diabrotica* will feed on fruit infected with brown rot and carry the disease to other fruit. The spreading of brown rot is probably as important as the feeding done by the beetle. In the case of canning fruit, small punctures or superficial feeding does not render the fruit worthless. Fruit that is too severely injured for canning but not badly infested with brown rot can be utilized for drying and juice.

The beetles may injure foliage, but this is hardly ever severe and probably never sufficient to justify control practices. Leaf feeding is most important on trees that have been planted recently. Such young trees may be heavily attacked but in all cases observed the trees have grown away from the injury without suffering apparent serious damage.

EXPERIMENTAL METHODS.—To determine populations in an orchard five to ten trees were selected at random. Sheets were placed under the trees. The sheets used varied in size from 18×18 feet to 24×24 feet. To facilitate placing them under a tree there was a slit half way down the middle. To determine the beetle population the trees were dusted with an insecticide containing pyrethrum. This knocked the beetles from the trees and they could be collected from the sheets and counted. Numerous tests were conducted to determine the efficiency of this method and it was found that, with proper precautions, all the *Diabrotica* in a tree could be removed. If an effective pyrethrum dust is applied when the air temperature exceeds 60° F., some of the beetles will fly from the tree. For most accurate counts, a temperature of 55° F. or lower is desirable.

In determining mortality, beetles were picked from the sheets and placed in paper bags with undusted foliage. At the end of 24 hours the beetles were examined. They were divided into three groups: (1) those that were definitely dead, (2) those that showed signs of life but were unable to fly and (3) those that appeared normal. The last group was counted as fully recovered, the second group was held for further examination, while the first group was used in determining mortality at the end of 24 hours. At the end of 48 hours, or sometimes later, the beetles of the second group were again examined and placed in dead and living groups. The dead were added to the number dead at the end of 24 hours, and the mortality for the 48-hour period determined. The bags con-

taining the beetles were kept in a room where the temperature never became excessive. This means of determining mortality proved to be the most satisfactory of several methods tried. Experiments were run in which the collected insects were caged on a tree or placed in screen cages with foliage in the branches of a tree. With screen cages in the orchard the mortality was slightly higher than where the beetles were placed in bags in the laboratory. The higher mortality may have been due to the direct, hot, sunlight on the cages. There was no satisfactory way to avoid this, and it was found that the most accurate method was to place the beetles in bags and hold them in a room as described above. Caged insects in a tree cannot move about freely and if conditions, where they are caged, become very unfavorable, they have no means of escape. We feel that the method used probably gave a conservative estimate of the actual mortality in the field.

Insects were always picked up by hand from the sheets for it was found that if they were shaken into the center of the sheet and then poured into a sack, the mortality was increased. This was unquestionably due to the fact that as they were being rolled into a pile they were covered with dust, which resulted in the death of most of the beetles.

In making field counts both a hand rotary duster and a power duster were used. A hand rotary duster was sufficient where the trees were small.

The amount of injury done by *Diabrotica* was determined by field counts usually for each of the different fruit pickings, and were based on what was found in the field boxes. Some counts were made in packing sheds. Injured fruit was divided into two catagories: (1) primary injury, which included the fruit that had been attacked by the beetle only; and (2) fruit that had been injured by other agencies, although also fed upon by *Diabrotica*.

Numerous control experiments were run to determine the most satisfactory conditions to apply dusts. It was found that temperature was a very important factor. To prevent most of the beetles from flying from the trees the dust had to be applied at temperatures below 60° F. At temperatures of more than 65° F. many of the beetles escaped by flying from the trees. No method has been discovered to determine what proportion of the beetles which fly out of the trees may be killed. At higher temperatures these insects leave the tree almost at the same instant the dust is applied.

The direction of dust drift is a very important consideration. To insure efficient control it is necessary that there be no drift or that it be into the area already dusted. A very small amount of an effective dust will cause the beetles to drop from the trees and if the drift is into the undusted portion of an orchard many beetles will be knocked out of the trees by a sub-lethal dose. The direction of drift should be determined accurately before dusting is started. Unfortunately, early in the morning the direction of drift is subject to rapid change, and for that reason dusting should be done in the shortest time possible.

A suitable duster should be able to develop sufficient velocity to push the dust through the tree. Also, the volume moved should be great enough so that the duster can be moved rather rapidly through the orchard. The duster used in the experimental work had an 18-inch fan and the type of nozzle that gave the best velocity and volume had a diameter at the intake of 4 inches and an outlet diameter of 6 inches. Aeroplanes can be satisfactorily utilized in dusting for *Diabrotica* control.

If a ground power duster is used, one row should be taken at a time. With a properly regulated duster it is possible to dust the trees efficiently from one side only. Under no conditions would it be advisable to treat both sides of a row because the first trip through would knock the beetles from the tree. It is also important to dust the rows consecutively. The equipment and orchard should be in such condition that the dusting may be done quickly and with no delays. If an aeroplane is used to apply the dust it is important that not more than two rows should be covered at a time, and care should be used to see that the drift is away from the undusted portion of the orchard.

Not all the insects fall out of a tree as soon as dust is applied. In a test of the rate at which the beetles fell from trees dusted with a power duster some interesting results were obtained. During the first five minutes after the tree was dusted 99 insects fell, 124 fell in the next four minutes, 58 in the next three, and 33 in the next

hour. Seventy-one per cent of the insects fell in nine minutes and over 96 per cent were down in 15 minutes. The temperature was constant (15.5° C.) during at least the first 12 minutes of these tests. Beetle mortality varied with the length of time the insects remained in the tree Of the first group to fall 31.3 per cent died, of the second 25.8 per cent, of the third 34.5 per cent, and of the last 42.2 per cent was killed. Apparently those insects which remained in the tree the longest showed the highest mortality. It is possible that the insects on the sunny portion of the tree are warmer, react more quickly to the dust, and fall from the tree. The colder insects are slower to react and consequently are subject to a larger dosage of dust.

Another very characteristic reaction of some individual beetles to dust is to vomit a relatively large amount of green fluid. In one experiment those individuals that made a green spot on the sheets were separated from those that did not. This was done for seven trees and in every case it was found that fewer of those insects which vomited died than those that did not. The average mortality for those which vomited (606 insects) was 83.5 per cent and for those which did not (1305 insects) was 92.5 per cent.

While several dust mixtures were used, the most effective materials contained pyrethrum. Because of the many factors involved, considerable difficulty was encountered in determining the effectiveness of any particular dust. Weather conditions, machinery used for application, size of tree, size of area treated, pounds per acre, speed of application, location of the orchard and rate of reinfestation all have an influence in determining the effectiveness of a given dust. Wherever possible, a number of tests was run. In a few cases entire orchards were dusted but in most experiments only about an acre of trees was involved. At intervals following dusting, counts were made in treated areas to determine population trends. The accompanying table presents some of the results obtained during the past year.

Dust mixtures experimented with most contained pyrethrum and *Lethane* (50 per cent $\beta$-butoxy, $\beta$-thiocyano diethylether) in talc or sulfur. These dusts all showed a great deal of promise. The amount of pyrethrum added was sufficient so that the pyrethrins content ranged from 0.05 per cent to 0.2 per cent, and the amount of *Lethane* ranged from 2 to 3 per cent. In several tests a slow acting *Lethane* was used, and while the kill obtained was not very satisfactory, final judgment on the dust should be reserved until further tests are made. Dusts containing 0.1 or 0.2 per cent of pyrethrins and 2 per cent of *Lethane* gave very good kills. Good kills were also obtained with dusts that contained 0.1 per cent of pyrethrins and about 3 per cent of *Lethane*.

Some work was done with pyrethrum dust to which a special solvent[1] had been mixed with the ground pyrethrum flowers. The carrier used was either sulfur or talc. Good control was obtained where the pyrethrins content of the dust was 0.1 or 0.2 per cent. Dusts of this nature need further investigation because, although a very good kill was obtained, the amount of dust used on an acre basis in experimental work was rather high. It is desirable that mortality be determined at lower dust dosages. Pyrethrum dusts to which no special solvent is added to the ground pyrethrum flowers were of little value for the control of *Diabrotica*.

Tests were conducted with a dust that contained 0.5 per cent rotenone and 2 per cent *Lethane* in talc, but the results obtained were very inconclusive. One of the complicating factors with this dust was that many of the beetles flew from the trees as soon as the dust was applied, despite favorable temperature conditions and it was impossible to determine the fate of these beetles. The mortality of those that fell to the sheets was moderately high, but all that can be said at this time is that such dust mixtures warrant further investigation.

Dust mixtures containing 2 or 3 per cent of dinitro-ortho-cyclo-hexyl-phenol gave poor kills and some burning of the foliage. Rather severe burn was caused by the 3 per cent dust in nectarine and apricot trees.

Where an effective dust was used there was a marked drop in the population. This was usually followed by a slight but gradual increase in number of insects. The increase can be attributed largely to beetles migrating into the dusted area

[1] Special solvents for finely powdered pyrethrum flowers tested included highly refined kerosene, *Lethane* and chlorinated, volatile petroleum, hydrocarbons, and combinations of the named solvents.

from the outside. Under ideal conditions a single dusting should give protection for at least 10 days, although in some cases beetles may migrate into a dusted area very rapidly. Where a valuable crop is to be protected, two dustings may be necessary. In cases where an infestation is severe, complete protection cannot be expected. Dusting under such conditions will only lessen the damage done but the reduction in insects will justify the cost of treatment because, without protection, an entire crop may be destroyed.

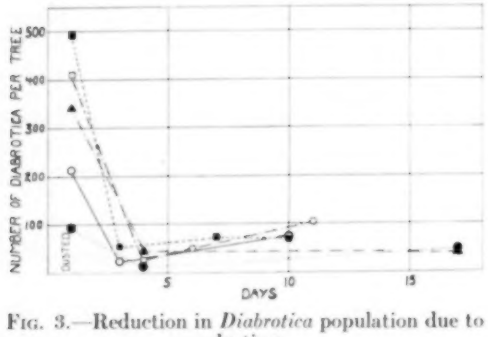


FIG. 3.—Reduction in *Diabrotica* population due to dusting

■ Ground pyrethrum flowers with special solvent in sulfur (pyrethrins 0.2 per cent) applied at 68 pounds per acre.

□ Ground pyrethrum flowers with special solvent in talc (pyrethrin 0.2 per cent) applied at 63 pounds per acre.

△ Ground pyrethrum flowers with special solvent in sulfur (pyrethrins 0.2 per cent) applied at 54 pounds per acre.

● 0.1 per cent pyrethrins and 2 per cent *Lethane* in sulfur applied at 36 pounds per acre.

○ 0.1 per cent pyrethrins and 2 per cent *Lethane* in talc applied at 50 pounds per acre.

Some of the results obtained, in terms of population reductions with five different dusts, are shown in figure 3. The dusts applied to small nectarine trees were as follows: (1) ground pyrethrum flowers with a special solvent in sulfur (pyrethrin content of dust 0.2 per cent) applied at the rate of 68 pounds to the acre; (2) same type of dust but with the pyrethrin content only 0.1 per cent, applied at the rate of 54 pounds to the acre; (3) ground pyrethrum flowers with special solvent in talc (pyrethrin content of dust 0.2 per cent) applied at the rate of 63 pounds per acre; (4) 0.1 per cent of pyrethrins and 2 per cent *Lethane* in talc applied at the rate of 50 pounds to the acre; and (5) the same type of dust but in sulfur applied at the rate of 36 pounds to the acre. All of these dust mixtures brought about a marked reductions in populations.

From the results shown in figure 3 it can be concluded that there are several dust mixtures that are efficient in reducing *Diabrotica* populations in orchards. However, reduction in population may not be sufficient to give full protection for, under certain conditions, the *Diabrotica* population after dusting may be as many as 50 to 100 beetles per tree. Such a population may cause considerable damage. An examination of figure 3 shows that in some cases the population was not reduced and held below this level.

There were several apricot orchards where the entire plantings were treated. In all cases the dust used contained 0.1 per cent of pyrethrins and 2 per cent of *Lethane* in talc. Control was obtained in all orchards although in one case it was necessary to dust twice and even then considerable damage was done to the fruit. Without any dusting the entire crop would have been severely injured. A cling peach orchard was dusted by aeroplane using the material at the rate of 50 pounds to the acre. Here the reduction in population was not all that might be desired. Considerable fruit was injured, but the treatment undoubtedly greatly reduced the extent of beetle attack. At the present time it appears that complete protection cannot be expected, although damage normally may be reduced sufficiently to repay a grower for the cost of treatment.

For satisfactory kills under good dusting conditions the minimum amount of dust to use per acre should be about 50 pounds. Mortality of *Diabrotica* at the end of 48 hours may reach nearly 100 per cent. With dosages above 50 pounds per acre an increase in mortality can be expected.

SUMMARY.—*Diabrotica 11-punctata* (Man.) has proved to be a very serious pest of ripening deciduous fruits. Losses are caused by direct feeding and through spreading of the brown rot organism.

Infestations of the beetles apparently arise from migrations of the pest from outside of the orchards. Trees with dense foliage are preferred as feeding places.

In the Brentwood region the highest populations in 1940 were encountered in the fringe of orchards adjacent to the uncultivated land. In some orchards the peak population per tree exceeded 700 beetles in 1940.

**Table 1.—Effectiveness of various contact insecticides used against *Diabrotica* on fruit trees—1940**

| MATERIAL | DATE OF DUSTING | TEMPERATURE DEGREES F. | POUNDS PER ACRE | AVERAGE NO. OF *Diabrotica* PER TREE | NO. USED IN DETERMINING MORTALITY | MORTALITY (24 HOURS) | MORTALITY (48 HOURS) |
|---|---|---|---|---|---|---|---|
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in talc | June 13 | 66 | 55 | 292 | 1444 | 73.9 | — |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in talc | June 13 | 50 | 45 | 196 | 1387 | 37.2 | 65.0 |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in talc | June 18 | 59 | 50 | 228 | 1140 | 55.5 | — |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in talc | June 20 | 61.7 | 50 | 171 | 684 | 89.0 | — |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in talc | June 20 | 61.7 | 80 | 217 | 435 | 100.0 | — |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in talc | June 29 | 60.8 | 50 | 180 | 1266 | 66.5 | 97.4 |
| Ground pyrethrum flowers (pyrethrins 0.05%) and 3% *Lethane* in talc | July 2 | 54.5 | 27 | 457 | 2285 | 50.5 | — |
| Ground pyrethrum flowers (pyrethrins 0.2%) and 2% *Lethane* in talc | July 5 | 58.0 | 38 | 238 | 1192 | 86.9 | — |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in talc | July 18 | 50.0 | 50[1] | 177 | 1238 | 70.7 | 84.4[2] |
| Ground pyrethrum flowers (pyrethrins 0.2%) and 2% *Lethane* in talc | July 19 | 59.0 | 53 | 434 | 2174 | 90.6 | 99.7 |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% slow acting *Lethane* in talc | July 19 | 62.0 | 50 | 272 | 1360 | 22.3 | 57.6[3] |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in talc | July 30 | 58.0 | 55 | 149 | 1044 | 84.7 | 98.5 |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in talc | July 31 | 50.0 | 60 | 371 | 1855 | 89.1 | 97.9 |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 3% *Lethane* in talc | July 31 | 57.0 | 50 | 265 | 1323 | 95.2 | 99.3 |
| Ground pyrethrum flowers (pyrethrins 0.2%) with special solvent in sulfur | Aug. 15 | 48.0 | 68 | 492 | 3445 | 71.1 | 99.7 |

[1] Applied by aeroplane—all others power duster.
[2] Final mortality = 96.8 per cent.
[3] Final mortality = 77.8 per cent.

**Table 1, Continued**

| Material | Date of Dusting | Temperature Degrees F. | Pounds Per Acre | Average No. of *Diabrotica* Per Tree | No. Used in Determining Mortality | Mortality (24 hours) | Mortality (48 hours) |
|---|---|---|---|---|---|---|---|
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in talc | Aug. 16 | 51.0 | 50 | 108 | 761 | 82.2 | 96.2 |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in sulfur | Aug. 16 | 56.0 | 60 | 36 | 253 | 88.1 | 94.8 |
| Dinitro-ortho-cyclo-hexyl-phenol 3% | Aug. 26 | 54.0 | heavy | 114[1] | 343 | 74.0 | 81.0 |
| Dinitro-ortho-cyclo-hexyl-phenol 2% | Aug. 26 | 54.0 | heavy | 63[1] | 127 | 22.0 | 33.0 |
| Ground pyrethrum flowers (pyrethrins 0.1%) with special solvent in sulfur | Aug. 28 | 59.0 | 54 | 319 | 2237 | 81.2 | 98.3 |
| Ground pyrethrum flowers (pyrethrins 0.1%) and 2% *Lethane* in sulfur | Aug. 28 | 59.0 | 36 | 93 | 651 | 57.9 | 63.8 |

[1] Some beetles flew from trees.

Because the beetles do not feed to any extent on green fruit, control measures are necessary only during the ripening period.

The most effective dusts used contain pyrethrum. A pyrethrum dust, to be effective, must have either some special solvent added or be used with some material such as *Lethane*. Effective dusts used had pyrethrin contents of 0.1 to 0.2 per cent and contained 1 or 2 per cent lethane or special solvent. To insure good control a dust should be applied at the rate of about 50 pounds to the acre. The temperature should not be higher than 63° F., and if there is any drift it should be into the area already treated. A drift into the non-dusted portion of an orchard will knock the beetles from the trees with a sub-lethal dosage. Under ideal conditions mortalities of from 90 to nearly 100 per cent can be expected.

For satisfactory control as many as two dustings may be necessary.—7-23-41.

## Pest Control Convention in San Francisco

The ninth annual convention of the National Pest Control Association will be held in San Francisco on October 27, 28 and 29 with headquarters in the St. Francis Hotel.

A general invitation has been issued to all persons interested in the problems with which the Association is organized to deal.

The program announced includes several topics of discussion which are of especial interest to entomologists and it is hoped that as many of these as possible attend the convention, not only for the benefit which may accrue to entomology but also as an expression of the very cordial relations which obtain between the Pest Control Association and the Association of Economic Entomologists.

## Cumberland-Shenandoah Fruit Conference

The annual Cumberland-Shenandoah conference to discuss the problems of research as they apply to the fruit industry of the district, will be held on November 21 and 22 at Winchester, Virginia. Headquarters will be the George Washington Hotel, where the meetings will be held.

Chairmen of the conference are Dr. A. H. Teske, of Virginia and Dr. S. A. Wingard. The section on Entomology and plant pathology will be presided over by Dr. A. B. Groves while Dr. W. S. Hough will act as secretary.

Visitors are welcome and discussions are informal.

# Some Characteristics of the Oriental Honeybee, *Apis indica* F., in China

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The Oriental Honeybee (*Apis indica* Fabricius), found throughout Japan, China, India, The Philippine Islands, Indo-China and the Malay Region, is one of the native honeybees of the Oriental Realm and, until the recent introduction of *Apis mellifera* L. from abroad, has been the main source of honey in these countries. From studies by the writer on specimens of these bees from the countries mentioned above, it is apparent that the largest individuals of this species occur in Fukien Province, in Southeastern China. These bees were identified as *Apis indica* var. *peroni* by Dr. T. Sonan, of the Government Research Institute in Taihoku, Formosa. Unless otherwise noted, the studies reported in this paper refer to this variety of *Apis indica*.

MEASUREMENTS AND DESCRIPTIONS.—*Length of body.*—Forty-one freshly killed worker bees measured from 10.5 to 13 millimeters in length, with a mean of 12.01 millimeters (in contrast to a mean of 13.57 for Italians), twenty bees in another series averaged 11.74 millimeters in length while in a third series, forty-three worker bees varied from 11 to 12 millimeters, with an average of 11.67 millimeters. Chang (1935) gives the body length of bees he studied in Canton, Kwantung Province, as varying from 11 to 14 millimeters, with an average of 11.82 millimeters, but these figures exceed those obtained by the writer from fifty bees sent to him from Canton, for they averaged 10.82 millimeters in length.

*Length of tongue.*—Measurements on 206 worker bees showed a tongue length (mentum and glossa) of 4.74 millimeters, in contrast to 6.25 millimeters for Italians.

*Size of right forewing.*—Measurements of 328 worker bees showed a length of forewing of 8.73 millimeters, a width of 3.01 millimeters and an area of wing ($\frac{1}{2}$ length $\times$ width) of 13.12 millimeters, as contrasted with the corresponding figures of 9.78, 3.31 and 16.186 millimeters for Italians (Kellogg, Robinson, Moss, Blackmer, 1939).

*Color.*—In color, the worker bees are distinctly a very dark brown, and ringed, with the first two to four abdominal segments showing brownish-yellow on their anterior edges. Both queens and drones are much larger than the workers and black in color, the drones also having peculiar twisted hind legs.

*Combs.*—The thickness of normal worker brood combs in naturally built combs is $\frac{7}{8}$ of an inch and there are 31.05 cells per square inch, while Chang (1935) reports from his studies of bees in Canton 33.55 cells per square inch for the worker comb and 23.47 cells per square inch for drone comb. Further, in the drone comb each cell, when mature, has a peculiar raised cone-like cap, perforated in the center with a tiny pore.

SIZE OF COLONY.—The usual local box hive used in the region about Foochow, Fukien Province, averages 12$\frac{1}{2}$ inches wide, 9$\frac{7}{8}$ inches high and 22$\frac{1}{2}$ inches long and contains 2690 cubic inches of space, as compared with a 10-frame Langstroth hive, which contains 2680 cubic inches of space. The most populous colonies seen by the writer in these box hives contained an estimated possible 55,000 to 60,000 bees, but the average size of colony should be placed at about 10,000 to 12,000 bees. Chang (1935) in Canton reports his smallest colony to contain 1500 bees, his largest one, 58,000 while the average number of bees per colony for two seasons was 6871 and 7710, respectively. Most colonies are kept small by continual swarming.

SWARMING.—Chinese bees are prone to swarm and this is difficult to control, as they seem to swarm irrespective of size of colony, congestion, or food supply. Chinese farmers do not try to control swarming (although they do remove excess queen cells to prevent after-swarming), but allow their bees to swarm at will, even priding themselves on the number of swarms produced! The bees in China do not have the migratory habits of the same species in India but they will abscond for almost any reason, as lack of food, ants, constant disturbances, unsatisfactory location, etc., sometimes even leaving young brood to starve. Swarms are easily captured and placed in box hives.

LACK OF SERIOUS DISEASES.—There are no records or reports, so far as the writer is aware, of serious indigenous brood diseases and he has never seen any sacbrood or foulbrood (of either type) among larvae of *Apis indica* or Nosema disease among the adults, although many examinations have been made. American foulbrood, however, was introduced into North China with the importation of Italian bees some time ago, and its ravages among these bees in the North are severe. The first and only case of American foulbrood seen by the writer in Fukien Province was in 1939 among Italian bees.

So-called "bare-headed brood" was encountered quite frequently among combs of *Apis indica*.

NON-RESISTANCE TO FOULBROOD.—As might be expected, *Apis indica* in the North is reported to be proving susceptible to the imported foulbrood and this will doubtless prove to be true also in South China, as the disease spreads, and may mean the virtual disappearance of the local bee.

DEFENSE AGAINST PREDATORY WASPS.—Chinese bees in the South have long been associated with several species of predatory wasps, *Vespa orientalis*, *V. cincta*, and *V. mandarina*, which are responsible at present for the greatest drawback to beekeeping in Southeastern and South China, and by that association the bees have learned the best ways of protecting themselves against such enemies. When the wasps appear, hovering in front of the hives, the small bees, no match for the great wasps, retire into the safety of the hives until the danger is over, or, if intercepted while returning to their hives, they will fly in a zig-zag manner to throw off their pursuers. In spite of the fact that these wasps often hover in front of the hives for hours at a time, the little bees often manage to elude them but the daily drain caused by the depredations of these wasps often so decimate the colonies that they do not recover, particularly since the period of the worst depredations corresponds with the summer period of dearth and cessation of brood-rearing. At times the bees will bravely attack the wasp, if it alights on the entrance board, in a body, "balling" it until death comes to the victim. *Vespa orientalis* feeds primarily on the bees themselves, carrying them up to a nearby tree, where the wasp, hanging head downward by one leg, cuts open the honey sac and extracts the nectar, while *Vespa mandarina* attacks the colonies mainly to rob out the honey, killing many bees in the attack, carrying off only a portion of them.

The Italian bees, on the other hand, are slow fliers and, unaccustomed to the wasps, fall an easy prey to the marauders. In each of several apiaries known to the writer, containing about one hundred colonies of Italian bees, a small boy was hired to watch all day long and "swat" wasps to keep them from the bees.

COMBS, WAX SECRETION AND PROPOLIS.—One trying habit of *Apis indica*, particularly with reference to its use in modern beekeeping, is that of chewing holes in old combs, often ruining them for future use. The bees seem to prefer to build new combs as needed, and, unless removed by the beekeeper, these old combs will be abandoned by the bees and left in the hives to attract wax moths. The bees are untidy housekeepers and the beekeeper must clean out the débris at frequent intervals—usually at least every ten days.

*Apis indica* far surpasses the western honeybee in the copious secretion of wax and the wax produced is of a fine consistency and a most beautiful white color. This has been referred to by many observers. Tokuta (1924) mentions wax scales on the Japanese variety of *Apis indica* of over one millimeter in thickness, causing a bulge in the covering plates of the abdomen.

Chinese bees do not use any propolis in their hives and the frames are always clean from this nuisance.

INDUSTRY AND ECONOMY.—The Chinese bee excels the Italian in industriousness, working earlier in the morning and later in the evening, in cooler and in more rainy weather, than the latter, and the rapidity with which it leaves the hive or the way in which it hurries into the hive on the return from the fields, places it in advance of the Italian bee for rapidity of movement.

A good characteristic of the Chinese honeybee is the way in which it will refrain from exhausting its stores in the dearth of the hot summer months or in the winter when it is too cool for flight, saving its stores against a time of need. The Italian bees will store more honey in

the spring but they use it up more rapidly during a dearth so that often they will be without food while the smaller and more parsimonious Chinese bees have food for sustenance.

PRODUCTION OF NEW QUEENS.—Tokuta (1924) is authority for the statement that in Japan, *Apis indica*, if deprived of its queen before queen cells are started, is unable to produce new queens from worker eggs. This is contrary to the experience of the writer in Southeastern China and Drieberg (1932) reports that *Apis indica* in Ceylon is able to rear queens from worker eggs.

MANAGEMENT.—The use of smoke from a bee smoker is standard practice in the control of Italian bees, but it is too drastic for the control of Chinese bees. Local beekeepers, with their bees in box hives, use only a small amount of smoke from a taper or incense stick gently to induce the bees to uncover a portion of the combs at a time or, when taking out honey, torches of dried grass are at times used (but not always) to drive the bees into the other end of the hive, but the writer has not seen a smoker of any kind used by Chinese beekeepers. The use of smoke from a modern smoker on *Apis indica* irritates the bees so that they fly wildly about and savagely attack the operator.

Reports on this subject differ widely. In the box hives the Chinese bees can with impunity be brushed aside with the fingers or forced to move by a little smoke from a taper, if one works slowly, and with *Apis indica* in modern hives it is often possible to inspect the bees without a veil, especially in the smaller colonies, but if the bees become irritated by sudden movements or too much smoke, they will attack furiously. The writer and his students have at times transferred colonies of these bees from box hives to modern hives, cutting out the combs and tying them in frames, without the use of veils or smoke, but at other times this has been impossible.

HELPLESSNESS AGAINST ITALIAN ROBBERS.—Chinese bees are unable to protect themselves against Italian robbers which often attack the former, both during the active spring season and the dearth of the hot summer season, causing the Chinese bees to abscond. For this reason it is impossible to rear the two species in close proximity and the experience in both China and Japan is that with the appearance of the Italian bees, *Apis indica* tends to disappear. However, it is interesting to note that, as the Chinese bees are more active in the cooler season, they will at times rob out their Italian competitors, as the latter are unable to protect themselves so well in the cool season. Chinese bees are inveterate robbers among themselves.

FAILURE TO RESIST THE WAX MOTHS.—One of the greatest faults of the Chinese bee is its failure to keep out the two species of wax moths (*Galleria mellonella* L. and *Achroia grisella* Fabr.), both of which occur in abundance in Southeastern China. This failure on their part necessitates, as stated above, constant care on the part of the beekeeper.

SUMMARY.—The Oriental Honeybee (*Apis indica* Fabricius), in spite of the introduction of the Italian bees and the presence of a number of commercial apiaries, is still the main source of honey for local consumption in China. It has for many centuries been reared in box hives,—the box hives of today being practically, if not literally, the same as those described in the earliest essay in Chinese literature dealing with honey production (A.D. 232), and during all of this time there has been no conscious change in methods or in selection of the bees until the very recent introduction of beekeeping methods and bees from the West.

The Chinese bees are small in size, the colonies are small, swarming is rampant, and modern manipulations are difficult because of the irritability of the bees, their aversion to smoke and their habit of chewing holes in old combs. These bees would have no place in this country as honey gatherers in competition with our bees but they do have the good qualities of industriousness; of flying in cool weather, which might be of value in the pollination of early fruits; and of copious secretion of a pure white wax, which would commend them for this particular function.—7-23-41.

# Observations on the Purported Resistance of the Honeybee to American Foulbrood

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It is not uncommon for a beekeeper to observe in a colony the presence of one or two cells of what appears to be American foulbrood and on the next examination discover that the cells have apparently been cleaned of all visible remains of the disease. In a majority of such cases, the disease will appear at a later date with greater severity while in a minor number of instances, it will not recur. In the latter cases the questions arise as to whether it was American foulbrood and, if so, was it a less virulent strain than usual or did the colony actually manifest a certain amount of resistance to the disease.

We are advised from various sources that American foulbrood is practically unknown in portions of Europe where bees have existed for centuries and we are led to believe from this that their strains of bees have developed resistance to the spread of this bacterial disease of their brood. Certain strains of bees are more resistant to European foulbrood than are others and this factor has been increased by careful selection and breeding. So it is only natural that those engaged in beekeeping should be ever hopeful of the discovery or production of strains of bees dependably resistant to American foulbrood.

In 1934 the American Bee Journal began to investigate the possibility of resistance to American foulbrood in various strains of bees and secured a number of colonies from different sections of the country, said by their owners to have shown an apparent resistance to the disease. During the first year they were able to claim that some strains of bees exhibit an evident resistance to the disease. A cooperative project was then established with the Iowa Agricultural Experiment Station to carry on more comprehensive tests and to investigate the possibility of increasing resistance through careful selection and breeding. Later, in 1937, queen-rearing yards were established in Texas with the cooperation of the Texas Apicultural Laboratory, the United States Bureau of Entomology and Plant Quarantine and the Texas and Iowa Agricultural Experiment Stations. The results of the first four years were summarized by Park, Pellett & Paddock (1939) as follows: "It is encouraging to note that, as a result of the careful selection and breeding practiced, there has been a constant and significant increase in the percentage of resistant offspring obtained year after year. It is not expected, however, that the increase in resistance will continue year after year at the same rate shown thus far. . . . The prospects now appear good for establishing a strain of bees that will produce resistant colonies in a high percentage of cases, but the problem will not be solved until resistance to American foulbrood has been combined with other desirable characters such as high production and good handling qualities. Years of selective breeding are still ahead."

In May 1940, the various cooperators decided to release some of the stock to different state agencies and beekeepers associations that wished to carry on further investigations or to produce queens for distribution to beekeepers. By January 1941, a few advertisements began to appear in bee journals of "American Foulbrood RESISTANT Queens." Up to and including May 1941 only one producer qualified his advertisement by stating that he made "no attempt to guarantee either expressed or implied, the resistancy of this stock" and this qualification was dropped after the first month.

On June 4, 1940, the writer received 12 queens of resistant strains from the Texas queen breeding station with no guarantee or record as to the relative resistance of the queens or of their stock. One queen was so severely crippled that she was not accepted on introduction into a nucleus. The queens were permitted to build up colonies in 3-frame nuclei, were transferred to one-story hives on July 11 and moved to another location. Shallow supers were added on August 15 and were filled with honey by September 28, with the exception of 3 colonies that did not build up as rapidly as the others. Empty comb space was added if needed, and the colonies were moved to an isolated location

on September 30th. Two days later each colony was given a brood comb which contained scales of American foulbrood in a majority of the cells, the combs being placed in the center of each brood nest. The colonies had brood in from $4\frac{1}{2}$ to 8 combs with brood in all stages. Brood-diseased brood. Thirty of these cells were placed in a queenless disease-free colony and 30 in a colony slightly infected with American foulbrood. Of this number, only 11 cells were completed in the diseased colony, of which number 9 contained larvae in the spinning stage that were dead

Table 1.—Data from fall examination of combs for symptoms of foulbrood.

| NUMBER OF QUEEN | FRAMES WITH BROOD | AMOUNT OF AMERICAN FOULBROOD 10/22 | FRAMES WITH BROOD | AMOUNT OF AMERICAN FOULBROOD 10/31 | COLOR OF QUEEN AND BEES |
|---|---|---|---|---|---|
| Z156 | 3 | 1 comb, 24 cells | 4 | 3 combs, many cells | Queen black, bees hybrid, cross |
| Z157 | 2 | 2 combs, 4 cells | 4 | 2 combs, many cells | Queen yellow, bees mostly 3-banded |
| Z159 | 3 | 2 combs, many cells | 3 | 3 combs, many cells | Queen yellow, fair grade of Italians |
| Z160 | 1 | No evidence | 0 | No evidence | Queen yellow, fair grade of "dark" Italians |
| Z161 | 2 | No evidence | 2 | No evidence | Queen yellow, bees hybrid, cross |
| Y66 | 2 | 1 comb, 5 cells | 2 | No evidence | Queen black, bees hybrid, nervous |
| Y67 | 2 | 1 comb, many cells | 2 | 2 combs, many cells | Queen black, bees mostly black, cross |
| Y68 | 3 | 2 combs, many cells | 3 | 3 combs, many cells | Queen black, bees black and hybrid |
| Y69 | 1 | No evidence | 1 | No evidence | Queen black, bees hybrid |
| Y71 | 2 | No evidence | 2 | No evidence | Queen yellow, bees hybrid |
| Y72 | 1 | No evidence | 1 | No evidence | Queen black, bees hybrid, nervous |

rearing was being retarded, especially in the colonies having darker bees.

On October 22, the inoculation combs of American foulbrood were removed and the colonies examined carefully on that date and again on October 31 for symptoms of American foulbrood with the results shown in Table 1.

The entrances of all colonies were then contracted to about 4 inches and each was wintered in a story and a half hive. Examinations during the spring of 1941 revealed the conditions detailed in table 2.

RESULTS OF REARING QUEENS FROM "RESISTANT" COLONIES.—Sixty queen cells were transferred from colony Z161 from a frame containing apparently healthy larvae scattered among cells of of American foulbrood (according to microscopic examination). Only 8 cells were completed in the disease-free colony and of these 4 contained dead larvae infected with American foulbrood. Several other cells in each case had been started but were torn down and the larvae removed. (The disease-free colony did not become infected although the bees were not "disease resistant.")

One hundred and eighty queen cells were then started from Z161 and Y68, selecting apparently healthy larvae, 24 hours or younger, from combs containing scattered cells of American foulbrood and they were completed in colonies that were broodless but with combs taken from previously diseased colonies. Of these cells,

only 82 were completed and 23 of them contained larvae dead of American foulbrood.

Thirty queen cells were then started from a disease-free colony and placed in a queenless colony having several combs badly infected with American foulbrood. Twenty-nine of these cells were accepted and sealed and of these 9 contained larvae dead of American foulbrood.

Four bars (60 cells) were next transferred from combs containing a scattering of diseased cells and two bars each were placed in disease-free colonies. One colony completed 26 of 30 cells, of which two contained diseased larvae, while the other colony completed 24 out of 30 cells, none of which were diseased. In the latter case, however, three additional cells had been started but were later torn down.

The sealed queen cells containing diseased larvae generally looked normal but the dead larvae could be observed through the cell walls when the cells were "candled."

DISCUSSION.—It is evident that while none of the colonies were dependably resistant to American foulbrood, following the method of inoculation used, some were "less tolerant" of the disease than others. From a practical standpoint, however, none of the colonies should have been maintained after the disease had gained headway or after the bees demonstrated their inability to clean their combs of the infected material. In previous experiments in testing the resistance of different strains, Park, and others, adopted a standard method of inserting a piece of comb 2 by 2½ inches in size with at least 75 cells containing infected material. The present tests included a far greater inoculative dose. The amount thus given would be greatly in excess of the amount of ma-

**Table 2.—Data from spring examination of combs for symptoms of foulbrood.**

| NUMBER OF QUEEN | FRAMES COVERED BY BEES 1/27/41 | AMOUNT OF DISEASE 1/27/41 | FRAMES COVERED BY BEES 2/25/41 | AMOUNT OF DISEASE 2/25/41 | REMARKS |
|---|---|---|---|---|---|
| Z156 | ½ of 4 frames | Many cells in 2 combs | less than 2 | Practically 100% | Colony destroyed, 2/25/41 |
| Z157 | 4 frames | No evidence | 9 frames | Several cells in 2 combs | 50% diseased, 5/14/41 |
| Z159 | ½ of 4 frames | Eggs only | 5 frames | Scattered cells in 1 comb | 7 combs badly diseased, 5/14/41 |
| Z160 | ½ of 5 frames | No evidence | 6 frames | 1 cell only | Gave infected comb, 2/25 considerable disease in 8 combs, 5/14 |
| Z161 | ½ of 4 frames | No evidence | 5 frames | No evidence | Gave infected comb, 2/25 50% diseased in 8 combs, 5/14/41 |
| Y66 | ½ of 5 frames | Many cells | 2 frames | 100% diseased | Colony destroyed, 2/25/41 |
| Y67 | ½ of 5 frames | Several cells | 2 frames | 75% or more diseased | Colony destroyed, 2/25/41 |
| Y68 | ½ of 5 frames | Few cells | 5 frames | Many cells in 4 combs | Built up in 2 shallow supers Much disease in 5 frames, 5/14/41 |
| Y69 | ½ of 5 frames | Many cells | 5 frames | At least 50% diseased | 75% diseased, 5/14/41 Colony destroyed |
| Y71 | ⅓ of 3 frames | Few cells | 3 frames | 75% diseased | Colony destroyed, 2/25/41 |
| Y72 | ½ of 5 frames | Many cells in 2 combs | 5 frames | Many cells in 2 combs | Badly diseased in 7 combs, 5/14/41 |

terial a colony would get under natural conditions.

The queens were permitted to lay in the brood chambers and shallow supers until April 24 when all but Z161 were confined to their brood chambers with queen excluders. This permitted the colonies to build up their numerical strength in the disease-free combs of the supers for a few cycles of brood but by April 24 the brood in these shallow combs also contained a considerable proportion of infected cells. At the time of the final examination, May 28, all of the colonies were so heavily diseased as to make their death seem merely a matter of time. The presence of some European foulbrood in Y72 and Z157, further complicated the disease situation for these colonies.

The infected queen cells, transferred originally from contaminated combs but drawn in disease-free colonies, indicated that the larvae must have been infected by the time they were transferred and that the disease did not prove fatal until, in some cases, the larvae had reached the spinning stage. This was shown to be the case for worker larvae by Woodrow (1941) who found that the period of susceptibility to American foulbrood corresponds with the period of mass feeding, and that infection is most likely to be produced when larvae are inoculated within approximately one day after hatching.

Woodrow also found that the larva has little or no resistance to the disease. This supports the theory that the apparent resistance of certain strains of bees to American foulbrood is based on a behavior factor or on the ability of these strains to remove the diseased material from the cells, a feat that most bees are unable to accomplish. In the present studies, there was some evidence of cells being cleaned of infected material before the bees stored honey in them and also before new brood was produced. This was done by the bees removing the infected material without tearing down the cell walls, except in two instances when a few of the cell walls were cut down to the midrib.

The term "resistant to American foulbrood" is misleading to most beekeepers because it raises a hope far more satisfying than it is possible for the bees to accomplish, particularly when colonies are subjected to such heavy inoculations as were used in these observations.

CONCLUSIONS.—Until more dependably resistant strains of bees can be produced by years of careful selection and breeding, beekeepers should not pin their faith on this strain of bees to solve their disease problem but should continue to eliminate all traces of American foulbrood by burning diseased colonies as soon as they are found.—7-23-41.

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## The Annual Meetings in San Francisco, St. Francis Hotel, December 29 to January 1, 1941

Plans are rapidly being completed for the winter meetings. At no time in our history has it been more desirable than it is this year to meet and discuss entomological work from the standpoint of its national aspects. Every effort is being made to provide for a profitable and enjoyable experience for everyone. A truly *national* meeting can be held only if entomologists from every section are in attendance.

It is the most sincere desire of those who are planning these meetings to be of service to every entomologist in matters of transportation, housing, and other details. Further informative material for general distribution is being prepared but it is obviously impossible to answer all questions which may arise. Please feel free to write us for personal help in planning your visit to the Pacific Coast.

Local Joint Committee on Arrangements
G. F. MACLEOD, *Chr. University of California, Berkeley, California.*

# SCIENTIFIC NOTES

## Type of Wire Screen Required for Excluding Cigarette Beetles and Tobacco Moths from Warehouses

J. P. VINZANT[1] and W. D. REED, *U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine*

For several years increasing interest has been manifested by the tobacco industry in the screening of warehouses and factories as an aid in the control of stored-tobacco insects. The screen first used was 18-mesh made of wire 0.011 inch in diameter. This screen was found to prevent the passage of tobacco moths, *Ephestia elutella* (Hbn.), but was not effective against cigarette beetles, *Lasioderma serricorne* (F.). As a result tests were made in 1940 with several grades of wire to determine the type best suited for use in warehouses and factories.

Cages 10 by 10 by 10 inches were constructed of different screens and test lots of cigarette beetle adults were placed in them. Three hundred beetles were used in each test. After a period of 21 days beetles that had not escaped were counted. The following screens and types of wire were used in the construction of the cages:

| Screen | Wire |
|---|---|
| 16-mesh | Steel, 0.011 inch, standard manufacture. |
| 18-mesh | Steel, 0.011 inch, standard manufacture. |
| 18-mesh | Steel, 0.011 inch, with coating of enamel over regular galvanizing, special manufacture. |
| 18-mesh | Steel, 0.011 inch, with extra coating of zinc over regular galvanizing, special manufacture. |
| 18-mesh | Brass, 0.016 inch, special manufacture. |
| 20-mesh | Steel, 0.0135 inch, not galvanized, special manufacture. |
| 20-mesh | Steel, 0.016 inch, not galvanized, special manufacture. |

An important consideration in the choice of wire screen is the cost. For example, the finest screen of standard manufacture obtainable is the 18 mesh made of galvanized wire 0.011 inch in diameter. This screen can be purchased in large lots for about 3 cents per square foot. The 20-mesh screen is of special manufacture and costs from 20 to 75 cents per square foot, depending upon whether it is made of steel, copper, or brass and upon the diameter of the wire. The extra coatings of enamel and zinc were added to the wires in the 18-mesh screen in an effort to reduce the size of openings and make this screen satisfactory.

The measurements of the cigarette beetle are about as follows: Length, maximum 3 mm., minimum 2 mm.; width, maximum 1.7 mm., minimum 1.3 mm. The average length is about 2.6 mm. and the average width 1.4 mm. The tobacco moth is larger than the cigarette beetle. The measurements are about as follows: Length, maximum 10 mm., minimum 9 mm.; width, maximum 5 mm., minimum 2 mm. The average length of the moth is about 9.46 mm. and the average width about 3.72 mm.

The tests showed that the 18-mesh screen of standard manufacture retained from 30 to 57 per cent of the cigarette beetles. The additional coatings of enamel or zinc proved to be of no practical value in preventing the escape of the beetles. The 18-mesh screen of 0.016 inch wire and of special manufacture retained about 90 per cent of the beetles. All cages made with 20-mesh screen retained 100 per cent of the beetles.

An opening smaller than 0.0396 inch in width is necessary to prevent the passage of cigarette beetles. This size of opening can be obtained with an 18-mesh screen made of wire 0.02 inch in diameter, which leaves an opening of 0.0355 inch. The 20-mesh screen of standard manufacture has a .0365 inch opening.

The average width of the cigarette beetle is about .0551 inch and that of the tobacco moth about .1465 inch. Therefore, the screen wire that prevented the passage of cigarette beetles was satisfactory in preventing the passage of tobacco moths.—7-28-41.

[1] Resigned September 15, 1940.

## Hogshead Construction as a Barrier to Stored-Tobacco Insects

W. D. REED, R. W. BRUBAKER and H. N. POLLARD, *U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine*

Cured tobacco is packed and stored in warehouses for periods ranging from about 1 to 4 years in order that it may reach the proper state of fermentation prior to manufacture. Most of it is packed in hogsheads which afford a partial barrier against stored-tobacco pests. These containers are ordinarily constructed 4½ feet high, 4 feet in diameter, and of pine, oak, or gum staves. Usually a hogshead has about 36 staves, ranging in width from 3 to 6 inches. The head is composed of 4 to 6 pieces. The container is held together by 6 wire hoops. Between the staves and the pieces in the head there are found cracks of various widths, the maximum being about 1 inch.

For several years storage warehousemen have made attempts to join or bevel the staves and heads of hogsheads to serve as a more complete barrier to insects entering or emerging from the tobacco. The increased cost of constructing such a hogshead is a factor of importance, and also the container must not be so tight as to interfere with aging or fermentation. This interest in the construction of tight hogsheads culminated in a private patent[1] which covered most of the structural features of the tight hogshead. This tight hogshead was made of closely fitted staves and a solid 1-piece head made of plywood. The number of staves was reduced to 18 and the container was held together with 2 wide metal hoops and 6 wire hoops. The number and size of cracks were greatly reduced between staves of the tight hogsheads and eliminated altogether in the heads. A crack as wide as one-fourth inch between the staves was rarely observed and in many cases the staves appeared completely sealed.

To test the effectiveness of the tight hogshead as a barrier to stored-tobacco insects, an experiment was conducted in 1940 which included two hogsheads of the old type of construction and two of the tight construction. About 1,000 pounds of flue-cured tobacco was redried and packed in each hogshead.

[1] U. S. Patent No. 2,127,435, April 16, 1938.

In the redrying process the tobacco temperature was raised above 160 degrees F. and all insect life was killed in the tobacco. The tobacco was of the 1939 flue-cured crop and of the identical type and grade. The hogsheads were redried and packed between

**Table 1.—Number of living larvae of the cigarette beetle and the tobacco moth found in tobacco samples from old- and new-type hogsheads.**

| Type of Hogshead | Sample | Number of Larvae | |
|---|---|---|---|
| | | Cigarette Beetle | Tobacco Moth |
| New | 15 hand | 76 | 0 |
| | | 439 | 0 |
| | 5 hand | 13 | 0 |
| | | 47 | 0 |
| | Sweepings | 11 | 0 |
| | | 11 | 0 |
| Old | 15 hand | 275 | 2 |
| | | 552 | 8 |
| | 5 hand | 10 | 0 |
| | | 30 | 0 |
| | Sweepings | 9 | 2 |
| | | 56 | 5 |

January 29 and February 5 and were placed in individual compartments of a cage in a tobacco warehouse in Richmond, Va., on April 15. The cage was made of a wooden frame covered with cloth having a thread count of 44 by 40 strands to the inch. The cage was 24 by 5 by 5 feet and each compartment was 6 by 5 by 5 feet.

Beginning on June 3 lots of the tobacco moth, *Ephestia elutella* (Hbn.), and the cigarette beetle, *Lasioderma serricorne* (F.), reared in the laboratory were released at intervals in each compartment of the cage until August 30. The total number released to infest each hogshead was 4,700 cigarette beetles and 1,100 tobacco moths. The hogsheads remained in the cages until December 3, at which time about all insect activity had ceased in the warehouse and the larvae of these insects were overwintering. The cages were dismantled and the hogsheads were inspected. Three samples of tobacco were taken from each hogshead, as follows:

(1) Every third hand of tobacco was taken from the cooper's end of the hogsheads until a 15-hand sample was obtained.
(2) A 5-hand sample was obtained from a break made near the middle of each hogshead.
(3) The outside surface of each hogshead was swept with a whisk broom and all scrap tobacco and insects accumulated there were retained as a sample.

The tobacco leaves in each sample were separated and screened and the living overwintered larvae counted. The sweepings from each hogshead were also screened and the living larvae counted. The results of the examination of the samples are shown in table 1.

The inspections made of the two hogsheads and of the samples collected indicate that tight hogsheads afford an effective protective barrier to infestation by the tobacco moth, but afford little or no protection against cigarette beetles. The damage was considerably greater on the surface of the old-type hogsheads, especially from feeding of tobacco moth larvae. The results obtained in this preliminary test demonstrate the need for further experimentation along this line.—7-28-41.

## Effects of Pyrethrins upon Blowflies

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The penetration of contact insecticides through the cuticle of insects and the consequent lethal effect should depend on the characteristics of the cuticle at the time of treatment. Immediately after molting or after emergence of the adult from the pupa the cuticle is softer and thinner than at other times. Therefore one might suppose that insects that have just cast their skins would be more susceptible to contact insecticides than those whose cuticle has hardened and thickened. Because the literature contains little information on this question, the writers were prompted[1] to make a few experiments on the relative susceptibility to pyrethrins of newly emerged and older blowflies, *Phormia regina* Meigen.

The pyrethrum insecticide used in these tests was a commercial product; namely, an ester of mannitan and coconut oil fatty acids containing 1% pyrethrins (A).[2] As a check the same product without pyrethrins was used (B).[3]

In each test the flies to be treated were enclosed in a cheese cloth bag and dipped for a period of 15 seconds in aqueous dilutions of A or B. Immediately after immersion, the bag was opened and the flies removed to a clean dry cloth pad. Within a few seconds the flies were transferred to 3-inch shell vials. The first test was duplicated, the others triplicated. Owing to the scarcity of newly emerged flies during the period of testing, only three flies were used per replication of each dilution. In a few instances four flies were used.

**Table 1.—Results of dipping *Phormia* flies of different ages.**

| Age of Flies | Test No. 1* 3 to 12 hours | | Test No. 2 Less than 5 minutes | Test No. 3* 36 to 48 hours | Less than 5 minutes |
|---|---|---|---|---|---|
| Material** | A | B | A | A | A |
| Dilutions | Per cent dead 48 hours after treatment | | | | |
| 1:100 | 100 | 83 | — | — | — |
| 1:200 | 100 | 100 | — | — | — |
| 1:400 | 100 | 67 | — | 100 | 33 |
| 1:800 | 100 | 33 | 10 | 89 | 11 |
| 1:1600 | 100 | 50 | 10 | 89 | 11 |
| 1:3200 | 88 | 17 | 0 | 33 | 0 |
| 1:6400 | 33 | 0 | 0 | 0 | 11 |
| 1:12800 | 14 | 17 | 0 | — | — |
| 1:25600 | 14 | 17 | — | — | — |

* No mortality occurred in water-dipped and undipped check lots.
** See footnotes 2 and 3.

[1] The general problem was suggested by F. L. Campbell, who assisted in the writing of this note.
[2] A = *NNOP*, Atlas Powder Co.
[3] B = *NNO*, Atlas Powder Co.

Results given in table 1 show (1) that B (a wetting agent) is toxic but that A (the same containing pyrethrins) is more toxic than B, (2) mortality caused by both A and B is related to concentration, (3) A is less toxic to flies that have just emerged than to older flies.

In the present tests the greater susceptibility of the older flies to pyrethrins is contrary to expectations, but is in line with the observations of Simanton & Miller (1938), who found that houseflies an hour old were less susceptible to pyrethrum-oil sprays than older flies, although the former were more readily paralyzed than the latter. With blowflies the present writers observed that the new flies were paralyzed more quickly and recovered more rapidly than the older flies.

Newly emerged blowflies may be more resistant than older blowflies either because the pyrethrins do not penetrate the new cuticle so readily or because the nervous system of the new flies has not reached its maximum susceptibility to pyrethrins. Injection experiments might illuminate this question.

The new flies were dipped before their wings had expanded. Those that recovered from pyrethrin paralysis were not able subsequently to expand their wings, which must have hardened while the flies were paralyzed. These and other flies that recovered were able to mate and lay fertile eggs.—8-4-41.

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## Control of Thrips on Seedling Cotton

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It has been known for a number of years that several species of thrips of the genus *Frankliniella* may be responsible for retardation of growth and malformation of seedling cotton plants. Such damage is characterized by the tightly curled and ragged young leaves. Although this injury has been noted in the Mesilla Valley for some time, it was especially severe in the spring of 1941, due probably to a protracted period of cool, wet weather. According to S. F. Bailey, University of California, who made determinations of specimens collected on cotton by the writers, the species concerned is *Frankliniella occidentalis* (Perg.).

It has been found by other investigators that tartar emetic and brown sugar is an effective control for gladiolus, citrus, onion, and bean thrips. Apparently this insecticide has not been tested for effectiveness against thrips on cotton. During the first week in June plots of a cotton field were sprayed with the following antimony compounds: (1) tartar emetic, 2 pounds; brown sugar, 5 pounds; in 50 gallons of water with 1 pint of *Dowax* added as a spreader. (2) A proprietary compound, sodium antimony lacto phenolate, 2 pounds; brown sugar, five pounds; in 50 gallons of water. A third plot was left untreated as a check. In 24 hours 20 plants were picked at random from each of the three plots, brought into the laboratory and counts of thrips were made on each plant. A second and third sampling was made 48 hours and 6 days later, respectively. There was no precipitation during the course of the experiment. These data are summarized in table 1.

**Table 1.—Thrips on seedling cotton, June 2 to 10, 1941.**

| TREATMENT | TOTAL THRIPS | MEAN | $\sigma$ | S.E MEAN | DIFF.[1] / S.E. OF DIFF. |
|---|---|---|---|---|---|
| 24 hours after treatment | | | | | |
| Check | 35 | 1.75 | 1.58 | .36 | |
| Tartar Emetic | 13 | .65 | .81 | .19 | 2.7 |
| S.A.L.P.[2] | 22 | 1.1 | 1.66 | .38 | 1.24 |
| 48 hours after treatment | | | | | |
| Check | 36 | 1.8 | 1.57 | .36 | |
| Tartar Emetic | 6 | .3 | .18 | .04 | 4.14 |
| S.A.L.P.[2] | 14 | .7 | .92 | .21 | 2.64 |
| Approximately one week after treatment | | | | | |
| Check | 51 | 2.55 | 2.44 | .56 | |
| Tartar Emetic | 14 | .7 | .87 | .20 | 3.1 |
| S.A.L.P.[2] | 12 | .6 | .68 | .16 | 3.35 |

[1] A ratio of 2 or more is significant.
[2] Sodium antimony lactophenolate.

FIG. 1. Left—treated plant; right, untreated plant.

By an examination of the table it is seen that plants in the treated plots showed a progressive decrease in thrips. When analyzed statistically the decrease was found to be significant as indicated by the ratio of the difference to the standard error of the difference. Apparently the effect of the compounds is residual, for after one week the treated plants retained a low thrips population.

Although it is not known whether the spraying of cotton seedlings is a practical procedure, it is shown by the experiment that a significant reduction in insect population can be obtained. Furthermore, the value of such control was reflected in the early recovery of the plant. Figure 1 illustrates a comparison between the size of an untreated and treated plant

one week after spraying. It may be seen that the treated plant is much larger and the new leaves are perfect, compared with the dwarfed and malformed condition of the untreated check.—8-6-41.

## Toxicity to the Codling Moth Larva of Phenothiazine Prepared with Allotropic Forms of Sulfur

E. H. SIEGLER and L. E. SMITH, *U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine*

Phenothiazine was first prepared for use as a possible insecticide in 1934. Since that time the compound has been extensively tested against various species of insects. In the course of this work entomologists have observed that their results varied markedly from season to season with different lots of the compound prepared commercially. In the hope of finding a possible explanation of these differences, comparative tests were made with phenothiazine prepared in the regular manner using amorphous sulfur, crystalline sulfur, and equal proportions of the two forms. Commercial sulfur was extracted by means of carbon disulfide. The residue from this extraction was regarded as amorphous. That portion soluble in carbon disulfide on evaporation of the solvent yielded crystalline material. These two fractions were used in this study.

**Table 1.—Comparative effectiveness of phenothiazine prepared with sulfur in various forms.**

| Form of Sulfur | Total Number of Apple Plugs | Percentage of Apple Plugs | |
|---|---|---|---|
| | | Wormy | Stung |
| Crystalline | 100 | 11.0 | 7.0 |
| Amorphous | 105 | 13.3 | 8.6 |
| Crystalline and amorphous in equal parts | 109 | 17.4 | 5.5 |

All three reaction products were found to be the same with respect to phenothiazine content, but the possibility existed of certain impurities being formed during the course of the reactions which might appreciably lower the toxicity of the resulting product. The reaction products appeared different with respect to color. The crude material was not purified but was ground in a mortar and then tested in the laboratory against the newly hatched codling moth larva, *Carpocapsa pomonella* (L.). The material was first dissolved in ethyl alcohol and then precipitated with 4 parts of water. The resulting suspension, at a concentration of 4 pounds of phenothiazine to 100 gallons, was tested by the apple-plug method (Siegler and Munger 1933, Siegler *et al.* 1934).

The form of sulfur used in the preparation of phenothiazine does not affect the toxicity of this insecticide to the codling moth larva, as shown by the data in table 1.—8-19-41.

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**Siegler, E. H.,** F. Munger, and J. B. Gahan. 1934. Improvement in "apple plug" technic for toxicological studies of the codling moth. JOUR. ECON. ENT. **27**(6): 1140–2.

## On the Causes of Peanut "Pouts"

F. W. POOS[1] *U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine*

For many years the cause of the widespread diseaselike injury of peanuts known as "pouts" has been attributed to various factors, such as soil conditions, boron deficiency, leafhoppers, and thrips. In 1938 S. B. Fenne, then of the Georgia Agricultural Experiment Station, submitted specimens of injured peanut plants from Tifton, Ga., on which thrips were found and identified as *Frankliniella fusca* (Hinds) by Floyd Andre, of the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture. Again, in 1939, Lawrence I. Miller, of the Virginia Agricultural Experiment Station, collected thrips in Nansemond County, Va., which he reported were apparently injuring peanuts and which he later suspected of causing "pouts." From this collection Dr. Andre identified *F. fusca* and *F. tritici* (Fitch).

Metcalf (1936) reported that peanut "pouts" is a disease transmitted by the potato leafhopper and that there are disease-free leafhoppers which produce merely a wilting of the leaves without any black discoloration. Metcalf (1937) attributed the cause of "pouts" to the potato leafhopper and said: "In the laboratory we have shown that the disease known as pouts is caused by what may be termed the mass effect of toxins." The only injury to peanuts observed by the writer to be caused by the potato leafhopper has been described and illustrated (Poos 1934; Batten & Poos 1938). This injury is readily distinguishable from the widespread injury known as "pouts."

In 1941 *Frankliniella fusca*, the tobacco thrips, was proved to be responsible for causing peanut "pouts." This diseaselike injury greatly inhibits development of peanut plants in the early stages and undoubtedly delays their development considerably. The true importance of it has not been determined. The growers refer to it as "pouts" because the plants are said to pout until they commence to bloom, at which time they begin to grow rapidly out of the injury. In the early stages of the development of the peanut plant many terminal buds are black in appearance as if they had been burned (Fig. 1). Less severe injury permits the leaflets to form normally in inverse proportion to the number of thrips present. Under field conditions as many as 28 immature thrips have been found between the folds of a single unopened peanut leaflet. Much of the feeding consists of rasping and scarifying the upper epidermis of the leaflet before the leaflet

[1] Grateful acknowledgment is due J. C. Crawford, of the Bureau of Entomology and Plant Quarantine, for all identifications of thrips referred to in this paper, except those otherwise credited.

unfolds, thus causing the scarred and gnarled or crinkled appearance of the irregularly formed leaflets after they have unfolded. The injury always appears on the upper surface of the leaflets. The degree of development attained by the leaflets apparently depends on their stage of growth when they are attacked and the number of thrips attacking them.

FIG. 1.—Typical injury of the leaves of peanuts, described as "pouts."

Immature thrips collected on the injured peanut plants in four widely separated Virginia localities were reared to adults and identified as *Frankliniella fusca*. During June this injury was observed throughout the peanut-growing areas of Virginia, North Carolina, South Carolina, and Georgia, from Fairfax County, Va., to Crisp County, Ga. In no case was the injury observed unless thrips were present. Collections of adult thrips were made from at least two localities in each of the previously mentioned States for specific identification in order to determine whether species other than the tobacco thrips were involved. *F. tritici* was also present in collections made at Macon, Ga., and Cheraw, S. C. It is possible, however, that other species of thrips may also be involved. The thrips were less abundant in areas which had recently had heavy rains than in areas which were in need of additional rainfall.

Adult thrips were extremely abundant in the peanut blossoms, suggesting the possibility that the adults may divert their attention to the blossoms when they appear rather than to the terminal buds, thus permitting more rapid growth of the plants. It is more probable, however, that there is a shift of the adult thrips to other hosts, or that climatic or other factors are involved.

FIG. 2.—Peanut "pouts" produced by thrips confined to plant at right; similarly caged uninfested plant at left. Arlington, Va., 1941.

Further proof that the injury is caused by the thrips was obtained in an out-of-door insectary at Arlington Experiment Farm in June and July 1941. In three tests young peanut plants produced the injury within a week after adult thrips (collected on peanuts) were confined on them under controlled conditions, whereas similar plants from which the thrips were excluded grew normally (Fig. 2).

Preliminary attempts to control this injury on peanuts by the use of tartar emetic-brown sugar spray, as recommended by McCulloch and Weigel (1941) for gladiolus, were not successful, but the tests were admittedly started too late to be valid.—8-29-41.

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## Effects of Infra-red Irradiation on the American Cockroach

G. F. MACLEOD, *University of California, Berkeley*

Considerable interest has been aroused by the appearance of a device purported to have a "lethal ray" which is particularly destructive to insect life. A few preliminary tests of this apparatus have been made and it seems desirable to record the results.

The essential feature of this equipment, is an incandescent lamp silvered inside on all but the seal-off end with an outside amber coating over the unsilvered portion. It contains a heavy, spiral fllament and fits into any normal lamp socket. The housing supplied for this lamp is of aluminum, lined with asbestos. The outfit operates from any 100-115 volt circuit Measurements of the energy in various regions of the spectrum when the lamp was operated at 115 volts gave a total of 254 watts with 163 watts in the infra-red, 55 watts in the visible and none in the ultra violet.

The lamp, in its holder was clamped to a ringstand so that a vertical beam could be used in all tests. All distances were measured from the seal-off tip of the lamp to the insect or plant and all exposures were timed with a stop-watch. Records of both the temperature at the surface of the insect and air temperatures just above the insect were kept in all tests because it was evident that there were marked differences. Adults of the American cockroach (*Periplaneta americana*) of comparable ages were used as test insects. All specimens were from a stock maintained for many generations in a constant temperature-humidity chamber and after treatment all of the insects were kept in the same chamber.

In the first tests at a distance of 18 inches from the lamp, adult roaches, irradiated on the ventral surface died in from 2½ to 4 minutes. The maximum air temperature was 26°C. and the maximum temperature at the surface of the insects was 43°C. In parallel tests irradiating the insects on the dorsal surface 4 to 6 minutes was required to kill the roaches whose tegminae reached a maximum of 47°C. while air temperature never exceeded 30.5°C.

A series of tests were conducted using a running water screen. The screen used was a tray of Pyrex glass 3 mm. in thickness holding 2 quarts of water. The water was 1¼ inches in depth and a constant flow was maintained. Insects were exposed at a distance of 18 inches for 10 minutes during which time the maximum air temperature was 21°C. and the temperature at the surface of the insect bodies was never above 25°C. None of these insects died and the females produced normal progeny.

Another group of insects irradiated on their venters for 1.5 hours at a distance of 40 inches from the lamp without a screen all died during treatment. In a second group similarly treated for 2 hours at 50 inches only 50% of the individuals died, some during treatment and some 5 days after exposure. Surface temperatures of the roaches in these trials reached 46°C. in the former and 42°C. in the latter test.

Necheles (1924) has shown that while roaches may die at 38°C. in moist air, they may survive at 48°C. in dry air. In all of these tests the humidity of the room was never above 30% relative humidity and an electric fan was kept in continuous operation blowing a large volume of air directly across all insects which were irradiated. Conditions for survival were therefore near optimum but no insects whose body surface temperature exceeded 40°C. during treatment in these tests survived.

In an effort to determine the possibilities of race death as a result of sub-lethal dosages of infra-red, groups of roaches were separated as to sex. One group was used as a control and neither sex treated, in another the males only were irradiated, in a third the females only were treated and in a fourth both males and females were irradiated. Each insect was given a separate treatment on the ventral surface. The dosage used was determined experimentally and set at a one minute exposure at 23 inches from the lamp. The insects were kept in groups of 10 females and 10 males in a container, with all containers held in the stock culture room and examined weekly. The results of this experiment, which was carried over a 45 day period, are shown in table 1.

While certain interesting trends are indicated in the data more extensive studies must be made before the true significance of these limited tests can be calculated. The body temperatures of irradiated roaches both male and female were about 10°C. higher than the temperature of the surrounding air. In no case did these temperatures approach a lethal point and only one out of the 780 roaches used died during the experiment. A high percentage of nymphs emerged from all the egg capsules produced.

The results in terms of water and food, or puppy meal, consumed per day are expressed on the basis of 20 insects. The group in which both males and females were irradiated consumed less water and more food than any of the others, but produced about the same number of egg capsules as those insects in which only the males were treated. Most marked deviations from normal occurred with the group where the treated females were kept with untreated males. There is no apparent explanation of the decrease in food and water consumed when the females only were treated as contrasted with the group in which both males and females were irradiated. Further studies are needed to establish the significance, if any, of these discrepancies.

**Table 1.—Results of treating cockroaches with sub-lethal dosages of infra-red radiation.**

| Treatment | | Maximum Temperature During Treatment | | Water Consumed: | Food Consumed: | Total Egg Capsules Produced |
|---|---|---|---|---|---|---|
| Males | Females | Air | Roach | Roach/day | Roach/day | per Female |
| None | None | — | — | 4.40 | .57 | 12.30 |
| Irradiated | None | 24°C | 33°C | 4.25 | .58 | 10.80 |
| None | Irradiated | 23 | 33 | 3.77 | .28 | 8.60 |
| Irradiated | Irradiated | 23 | 35 | 2.97 | .65 | 10.70 |

All trials with insects on plants which have been made indicate that the plants were injured before the insects feeding on them were killed. Tests of mites, mealybugs, aphids and white-flies on several plants have been made in the greenhouse. In every case dosages which killed the insects destroyed or seriously injured the plants. While possibilities of establishing a safety differential in favor of the plant have not been exhausted, the probability of doing so seems remote at present.

SUMMARY.—An incandescent lamp capable of producing and focusing a large amount of infra-red radiation was used to kill adults of the American cockroach. The insects were killed by a 2½- to 4-minute exposure of the ventral surface to radiation from this lamp at a distance of 18 inches. Double this dosage was required to kill the insects when they were treated on the dorsum. When roaches were irradiated through a water screen, which removed a large part of the infra-red, none of them were killed.

In an experiment to test the possibility of race death resulting from sub-lethal dosages of radiation, most marked deviations from normal occurred when irradiated females were placed with untreated males. No general trend toward race death as a result of the treatment was apparent.

All attempts to date to kill insects on plants have resulted in injury or death of the plants before the insects were killed.—6-30-41.

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## *Program Problems*

How to get members out of the corridors and into meetings is a problem which has perplexed program committees for years. During sessions the average member spends approximately half of his time attending symposia and listening to other papers in which he is particularly interested and the other half talking to fellow members outside the meeting rooms. As a result the corridors and hotel lobbies are filled with animated groups ardently discussing topics of mutual interest, while in the auditoriums the speakers address the faithful few who have honored them with their presence. Reasons for this condition are the natural desire to discuss one's own problems with other workers in the same field and the lack of general interest in the majority of papers presented. Many members state frankly they get more benefit from informal discussions in the halls than from listening to the average paper, which all too frequently is a dull and lengthy recital of the life history of some insect and its reaction to standard insecticides. The same members, no doubt, are disappointed by the small audiences when it comes their turn to present papers. Probably no member would go so far as doing away with formal papers or eliminating informal discussions entirely.

Recognition of the inherent values of both informal discussions and prepared papers and arrangement of sessions so there will be a place for each without direct competition seems to offer the most likely solution of our program problem. Providing opportunities for informal discussions of specialized topics would necessitate reducing the time spent in presenting papers. This could be done by having authors of all except invitational papers present abstracts and perhaps slides or charts to bring out the highlights of their manuscripts. This should be enough to invite questions and promote discussions from the floor on papers of real merit. Placing manuscripts on file with the secretary, or in a special room, would allow closer study of detailed data by those especially interested. Such a system offers every member an opportunity to present the results of his work to the Association and at the same time relieves those attending the sessions from listening to uninteresting, time-consuming details. The time saved could be devoted to longer discussions of papers presented in abstracts and to informal group meetings at specified times and places. If formal programs closed in mid-afternoons those interested in the design of field experiments and statistical methods, biological control, vector-virus studies, quarantines, insecticide investigations, pea weevil, codling moth, grasshoppers, or other special topics, could gather in rooms designated by the Secretary where informal discussions could continue as long as desired. Several group discussions of this nature held at Philadelphia were heartily indorsed by those attending. The program committee is planning greater opportunity for such meetings at San Francisco and is considering the changes suggested above as a means of providing the necessary time.

By encouraging discussions and eliminating uninteresting details from regular sessions and by providing opportunity for members interested in special problems to meet and talk informally, the program committee hopes to increase attendance at meetings and decrease the number of members usually found in the corridors and hotel lobbies. The interest and support of all members is needed to attain these objectives.

J. R. Parker

# PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL MEETING

## PACIFIC SLOPE BRANCH

## AMERICAN ASSOCIATION OF ECONOMIC ENTOMOLOGISTS

### California Institute of Technology, Pasadena, California
### June 18, 19, 20, 1941

The Twenty-sixth Annual Meeting of the Pacific Slope Branch was highly successful, both as to quality and variety of papers presented and as to attendance, which totaled 335. Of the 57 papers and 8 formal discussions listed on the program, only 3 authors were not present. Each session started with an invitational paper of special interest. The Wednesday sessions and that of Friday p.m. were devoted to papers on a wide variety of entomological topics. On Wednesday night there was a symposium on the topic "Relationships Between Systematic and Economic Entomology" which was of sufficient interest to draw an attendance of 145. The outstanding session was on Thursday, which was a symposium on "Petroleum Oil Sprays on Deciduous and Citrus Fruit Trees." Friday morning was devoted to "Problems in Western Forest Entomology." The entomological dinner, held Thursday night, with an attendance of 278, was devoted exclusively to dining and entertainment.

Officers elected for next year are: Chairman, GEO. F. KNOWLTON, *Logan, Utah;* Vice Chairman, JAS. C. EVENDEN, *Coeur d'Alene, Idaho;* Secretary-Treas., ROY E. CAMPBELL, *Alhambra, Calif.* It was announced that the 1942 Pacific Slope Branch meeting would be in Salt Lake City. The following members were among those present:

| | |
|---|---|
| Bailey, Stanley F. | Davis, California |
| Bartlett, Blair R. | Riverside, California |
| Bohart, Richard M. | Los Angeles, California |
| Boissonou, Clifford J. | Martinez, California |
| Boyce, Alfred M. | Riverside, California |
| Boyden, B. L. | Whittier, California |
| Broadbent, Bessie M. | Whittier, California |
| Brooks, James W. | Madison, Wisconsin |
| Campbell, R. E. | Alhambra, California |
| Cecil, Rodney | Ventura, California |
| Chauvaud, E. Maurice | Santa Ana, California |
| Cook, William C. | Modesto, California |
| Craig, Roderick | Berkeley, California |
| Cressman, Albert W. | Whittier, California |
| DeBach, Paul | Riverside, California |
| Dickson, R. C. | Riverside, California |
| Dohanian, S. M. | Eugene, Oregon |
| Doucette, C. F. | Sumner, Washington |
| Duggan, Chas. E. | Pomona, California |
| Ebeling, Walter | Riverside, California |
| Eckert, J. E. | Davis, California |
| Elmore, J. C. | Alhambra, California |
| England, Max H. | Covina, California |
| Essig, E. O. | Berkeley, California |
| Ferris, Curtis A., Jr. | Upland, California |
| Flanders, Stanley E. | Riverside, California |
| Flebut, A. J. | Berkeley, California |
| Freitag, Julius H. | Berkeley, California |
| Fulton, Robert A. | Whittier, California |
| Gammon, Cyril | Altadena, California |
| Gammon, Earle T. | Pasadena, California |
| Hansen, James W. | Berkeley, California |
| Henderson, Charles F. | Whittier, California |
| Hensill, George S. | Richmond, California |
| Herms, William B. | Berkeley, California |
| Hills, Orin A. | Phoenix, Arizona |
| Holloway, James K. | Whittier, California |
| Hutchison, Robert N. | Covina, California |
| Johnson, Esler | San Francisco, California |
| Kagy, J. Franklin | Riverside, California |
| Kellogg, C. R. | Pasadena, California |
| Kido, George S. | San Jose, California |
| Kirkpatrick, Albert F. | Monrovia, California |
| Kitchel, R. L. | San Dimas, California |
| La Follette, J. R. | Whittier, California |
| Landon, William E. | San Dimas, California |
| Lange, W. H., Jr. | Berkeley, California |
| Lingren, David L. | Riverside, California |
| Linsley, E. Gorton | Berkeley, California |
| Mackie, D. B. | Sacramento, California |
| MacLeod, Guy F. | Berkeley, California |
| Mallis, Arnold | Los Angeles, California |
| Mason, A. C. | Honolulu, T. H. |
| Maxwell, K. E. | Martinez, California |
| McGregor, E. A. | Whittier, California |
| McKenzie, H. L. | Berkeley, California |
| Michelbacher, A. E. | Berkeley, California |
| Mitchell, James H. | Pomona, California |
| Morrill, A. W. | Glendale, California |
| Morrison, H. E. | Corvallis, Oregon |
| Mote, Don C. | Corvallis, Oregon |
| Munger, F. | Whittier, California |
| Parker, W. B. | Placerville, California |
| Penny, D. D. | Whittier, California |
| Persing, Charles O. | Riverside, California |
| Pierce, W. D. | Los Angeles, California |
| Richards, Claude A. | Montebello, California |
| Ryan, Harold J. | Los Angeles, California |
| Salman, Kenneth A. | Berkeley, California |
| Schuh, Joe | Corvallis, Oregon |
| Scott, David B., Jr. | Tacoma, Washington |
| Sheldon, Howard B. | Santa Paula, California |
| Silva, Pedrito | Bahia, Brazil |
| Smith, Gordon L. | Shafter, California |
| Smith, H. S. | Riverside, California |
| Smith, Leslie M. | San Jose, California |
| Smith, Ralph H. | Los Angeles, California |
| Snow, Charles A. | Whittier, California |
| Sorenson, Charles J. | Logan, Utah |
| Stafford, E. M. | Fresno, California |
| Steinweden, John B. | Sacramento, California |
| Stewart, Morris A. | Davis, California |
| Stone, M. W. | Ventura, California |
| Swain, A. F. | El Monte, California |
| Swezey, O. H. | Honolulu, T. H. |
| Timberlake, Philip H. | Riverside, California |
| Todd, Frank E. | Davis, California |
| Urbahns, T. D. | Uba City, California |
| Usinger, Robert L. | Davis, California |
| Vansell, George H. | Davis, California |
| Vaughn, William C. | San Marino, California |
| Wampler, Elvin L. | El Segundo, California |
| Wilcox, Joseph | Alhambra, California |

| | |
|---|---|
| Woglum, R. S. | Los Angeles, California |
| Yuill, J. S. | Berkeley, California |
| Yust, Harold R. | Whittier, California |

BUSINESS SESSION.—At the final business session, the following motion and resolutions were unanimously passed:

It was moved that the Chairman appoint a Committee to investigate the desirability, cost, and practicability of publishing a Western Directory of Entomological Supplies, Equipment, Insecticides, Etc., and that this committee be empowered to act if the proposition is found to be entirely feasible, or if further consideration is desired, to make a full report with recommendations to the meetings of the main association at San Francisco in December, 1941.

*Resolutions*

1. "Whereas the California Institute of Technology at Pasadena has generously allowed us the use of its fine facilities for our meetings, June 18, 19, and 20, 1941, be it resolved that the Pacific Slope Branch of the American Association of Economic Entomologists express its gratitude by a communication to the head of the Institution."
2. "Whereas the program and arrangements of the June 18, 19, and 20, 1941 meetings of the Pacific Slope Branch A.A.E.E. have been instructive and interesting . . . Be it resolved that those in attendance express their appreciation of the organization of these meetings to the officers of the division."
3. "Whereas Dr. Lee A. Strong, who entered entomological work in California, contributed greatly to the development of entomology in all its branches as Chief of the United States Bureau of Entomology and Plant Quarantine, and whereas in the passing of Dr. Strong, entomology in North America has sustained an irreparable loss. . . . Be it resolved that the Pacific Slope Branch of the American Association of Economic Entomologists express to Mrs. Strong its sincere esteem of Dr. Strong's contribution to the advancement of entomology and of his unselfish devotion to its development."
4. "Whereas the summer sectional meetings and symposia of the American Assn. for the Advancement of Science are usually of considerable interest and importance to entomological workers throughout the country. . . . Be it resolved that the Pacific Slope Branch of the A.A.E.E. petition the Executive Committee of the main organization at the San Francisco meeting, that an attempt be made to synchronize the dates of the summer meetings in order to eliminate competition, especially when subject matter of the sectional meetings or symposia are of national interest and importance."
5. "Whereas the International Rules of Zoological Nomenclature have proven inadequate in many pressing matters of entomological nomenclature, and whereas the field of entomology has many nomenclatural problems peculiar to itself, and whereas present world conditions make it appear extremely unlikely that the International Commission of Zoological Nomenclature will be able to function effectively for many years to come. . . . Be it resolved that the Pacific Slope Branch of the A.A.E.E. petition the parent society as well as the Entomological Society of America and all other entomological groups, that a committee be formed representative of the various North American entomological organizations, institutions, and geographic areas to consider the present status of entomological nomenclature and the advisability of extending the International Rules of Zoological Nomenclature in the form of an Entomological Code."
6. "Whereas the insect and mollusk collections at the Los Angeles Museum are an integral part of the development of west American Entomology and Conchology

   Whereas the research maintained in connection with these collections is of inestimable value in connection with the growth of western entomology and the protection of California agriculture

   Whereas a research biological collection and the true value thereof is ruined by either being deprived of the connected research, or by the dispersion of the collection, or both

   Whereas there are already too few west American collections of this type and too little taxonomic research. . . . Be it resolved that the secretary of the Pacific Division of the A.A.E.E. immediately petition the Board of Supervisors of Los Angeles County and the Board of Governors of the Los Angeles County Museum to maintain the Entomological and Conchological collections of the Museum, and the connected research positions as they are now constituted."
7. "Whereas taxonomic knowledge of insects is a fundamental part of the development of other branches of entomology, and whereas insect taxonomy is very poorly organized due to the lack of professional positions and the lack of financial support. . . . Be it resolved that the Pacific Slope Branch of the A.A.E.E. petition the American Association of Economic Entomologists at the next annual meeting, to form a standing committee for the development of insect taxonomic research not only in its morphological but also its experimental aspects."

REPORT OF THE TREASURER, 1940–41

(Condensed)

| | | |
|---|---|---|
| Balance on hand, July 5, 1940 | | $11.22 |
| Interest | | .23 |
| Refund for 1940 expenses | | 53.16 |
| Express | .46 | |
| Stamps | 1.00 | |
| Envelopes (stamped) | 16.12 | |
| Mimeographing notices & programs | 31.00 | |
| | 48.58 | |
| Balance on hand June 18, 1941 | 16.03 | |
| | $64.61 | $64.61 |

Accounts audited and approved by
A. E. MICHELBACHER
C. O. PERSING

ROY E. CAMPBELL
Secretary-Treas.